

13 PHOTOGRAMMETRY SURVEYS

Photogrammetric surveys establish targeted, and occasionally non-targeted, photo control on the ground to relate aerial photographs to a project's horizontal and vertical datums.

The photo control is used by the Office of Photogrammetry (OoP) to create topographic and planimetric maps for Design, Environmental, Traffic, Hydrology, Planning, and other functional units within the Department as well as by consultants.

This chapter is to be used for Department-involved transportation improvement projects, including special funded projects. It shall be used by all Department employees, local agencies, and consultants performing photogrammetric tasks. It is their responsibility to adhere to all relevant processes, workflows, and specifications stated in this chapter. Questions about this chapter should be discussed with the District Photogrammetry Coordinator (DPC), Surveys, and/or the Contract Manager.

This chapter provides policies, general information, and procedures regarding the photogrammetry process. It describes a statewide model of responsibilities and workflow. Unique circumstances in a project may warrant deviations from this model. The Survey Manager, DPC, and the OoP Manager will jointly agree upon any modifications to the model.

13.1 Policy

It is the Department's policy that a photogrammetric survey shall be requested as early as possible in a project to ensure a timely delivery of the final product from OoP.

It is also the Department's policy regarding photogrammetric surveys to provide photo control in a timely manner, surveyed to all of the requirements in the Department's Surveys Manual for use by OoP in producing topographic and planimetric maps.

Additionally, it is the Department's policy to examine emerging photogrammetric methods for potential use by the Department. As the newly developed photogrammetric methods are adopted by the Department, new specifications will be developed and existing specifications will be changed.

13.2 General Information

Photogrammetry Defined

Photogrammetry: *The art, science, and technology of obtaining reliable information about physical objects, and the environment, through processes of recording, measuring, and interpreting images and patterns of electromagnetic radiant energy and other phenomena. (Manual of Photogrammetry, 4th Ed., ASPRS, 1980)*

13.2-1 When to Use Photogrammetry

Each project has a unique set of conditions that will determine which mapping techniques should be utilized. Surveys in consultation with the Project Manager will determine if photogrammetry will be used on a project.

The following are factors to consider when deciding to use Photogrammetry:

- Photogrammetry is a cost efficient surveying method for mapping large areas.
- Photogrammetry may be safer than other surveying methods. It is safer to take photographs of a dangerous area than to place surveyors in harms way.
- Photogrammetry provides the ability to map areas inaccessible to field crews.
- Photogrammetry creates a photographic record of the project site (snapshot in time).
- Photogrammetry produces useful digital products such as orthophotos.
- Photogrammetry produces electronic terrain models.

13.2-2 When Not to Use Photogrammetry

Photogrammetry is not the solution for all mapping situations. Photogrammetry may not be appropriate under the following conditions:

- The accuracy required for a mapping project is greater than the accuracy achievable with photogrammetric methods.
- The scope of the work is not large enough to justify the costs of surveying the photo control and performing the subsequent photogrammetric processes. However, when unsafe field conditions are encountered, safety shall hold a higher weight than cost in the decision process.

13.2-3 Caltrans Photogrammetry Information Sources

In addition to this chapter, there are several sources for information on photogrammetry within the Department.

- The first and foremost is the DPC. The DPC is familiar with the products and services that can be obtained through photogrammetric techniques. The DPC is also familiar with OoP staff and which staff members to contact for answers to specific questions.
- The second source is OoP's publication, *User's Guide to Photogrammetric Products and Services*. This guide provides information and guidance for those in need of mapping or other photogrammetric products.
- The third source is OoP's intranet web site at:
<http://onramp.dot.ca.gov/hq/esc/et/photogrammetry/index.shtml>
- OoP also has a web site accessible via the internet at:
<http://www.dot.ca.gov/hq/esc/geometronics/PHOTOGRAMMETRY.HTML>

13.2-4 Photogrammetric Products Available

The following list summarizes photogrammetric products available from OoP.

- New Aerial Photography: Precision photography as well as general photography.
- Photo Reproduction and Enlargement: OoP provides photography lab services for reproduction and enlargements of images captured on conventional aerial film.
- Topographic Mapping: Precision maps used for project studies, project design, and other purposes are compiled as three-dimensional vector representations of permanent features and terrain, provided in the Department's standard CAD format.
- Digital Terrain Models (DTM): Three-dimensional digital surfaces of the terrain derived from topographic mapping and often combined with field data provided in the Department's standard DTM format. The document, "Standard Delivery Format for Precise Field Surface Data" can be located at OoP's intranet web site.
- Scanning: OoP has a high-resolution, high accuracy aerial film scanner suited for large volume scanning of roll film.
- Descartes Rectification: Simple digital rectification of photographs to known ground positions, such that the resulting digital images can be used for public display and other non-engineering tasks.

- Digital Orthophotography: High accuracy digital images produced from stereo photography and digital terrain information that can be used with reliability approaching that of conventional photogrammetric mapping.
- Digital Highway Inventory Photogrammetry Program (DHIPP): Provides intranet accessible geo-referenced ortho-rectified digital color aerial images of the California highway system for non-engineering applications.
- Satellite Imagery: High altitude, low-resolution images are available from remote sensing satellite operators, and are appropriate for public displays and other non-engineering functions.
- Light Detecting and Ranging (LIDAR): LIDAR provides a high density digital elevation model of a site by using an airborne laser to scan the terrain producing a large number of geo-referenced points.

13.3 Responsibilities

Teamwork is vital for the efficient completion of the photogrammetric mapping process. The following list illustrates the necessity of communication and teamwork by detailing the responsibilities of the staff involved in the photogrammetric mapping process.

13.3-1 Project Manager

The Project Manager leads the Project Development Team and is responsible for overall project planning and completion.

It is the responsibility of the Project Manager to:

- Facilitate communication between all parties involved in a project.
- Develop the Project Workplan (schedule and resources) with input from functional managers.
- Open the appropriate project phases.
- Work with the DPC to ensure that the expenditure authorization and special designations are in place before work begins.
- Establish and communicate the priority of the project within the District/Region.
- Coordinate with OoP and other functions to ensure timely delivery of photogrammetry products.
- Ensure that the Request for Surveying and/or Photogrammetric Services is submitted in a timely manner.
- Negotiate and communicate the timetable for the final delivery of the photogrammetry products with the functional units.
- Monitor the progress of the project.
- Notify the DPC of any changes in the project that may affect the scope, schedule, or resourcing of the photogrammetry products.

13.3-2 Design Engineer

The Design Engineer is responsible for overseeing the design of transportation facility improvements.

It is the responsibility of the Design Engineer to:

- Confer with the DPC regarding project requirements.
- Submit a Photogrammetric Service Request form to the DPC for all required photogrammetry products in a timely manner.
- Determine the limits of the area to be mapped and to communicate those limits at the beginning of the photogrammetry project.
- Determine the limits of the DTM, if needed, and if those limits are different from the mapping limits.
- Review and accept delivery of photogrammetric products from the DPC.

13.3-3 Surveys

It is the responsibility of Surveys to:

- Ensure that field crews have been trained in the proper techniques for setting photo control targets and establishing values on the photo control.
- Ensure that field crews have access to the Department's Surveys Manual.
- Ensure that resources are assigned to photogrammetry projects in a timely manner.
- Ensure that the marked control prints and the photo control are checked and delivered to the DPC in a timely manner.
- Stay in communication with the DPC on all issues related to the progress of the photogrammetric project.
- Manage all imagery and photogrammetric products stored within the District/Region.

13.3-4 Party Chief

The Party Chief functions as a first line supervisor responsible for overseeing the work of a survey field crew.

It is the responsibility of the Party Chief to:

- Ensure that the accuracy standards stated in Chapter 5 of the Department's Surveys Manual for photogrammetry surveys are met when establishing photo control.
- Ensure that the specifications for surveying photo control set forth in the Department's Surveys Manual are followed.
- Ensure that photo control targets are established at the positions or within the positional tolerances indicated on the flight plan or in the positions agreed upon with the DPC.
- Maintain communication with the DPC on any issues or concerns related to photo control.
- Survey, if practical, all photo control prior to acquiring photography.
- Ensure that all photo control targets are in place immediately prior to the scheduled aerial photogrammetry flight.

13.3-5 District Photogrammetry Coordinator (DPC)

The DPC is a surveyor who serves as the liaison and single point of contact between OoP and District functional units concerning photogrammetric issues.

It is the responsibility of the DPC to:

- Coordinate photogrammetry related activities within the District.
- Coordinate the District/Region's photogrammetric needs in emergency situations.
- Work with the Project Manager to ensure that expenditure authorization and special designations are in place before work commences.
- Confer with the Design Engineer concerning photogrammetric products, either existing or to be produced, required for a project.
- Attend District Project Development Team meetings and consult with the team on photogrammetric products and services that may be required for a project.
- Assist in the preparation of Photogrammetric Service Requests.

- Assist OoP in establishing photogrammetry project priorities within the District.
- Notify the Project Manager of any changes in the photogrammetric products and services that may affect the scope, schedule, cost, or resources for the project.
- Attend and participate in the annual DPC's meeting and all DPC teleconference meetings.
- Act as the liaison for questions, concerns, materials, and information between District staff and OoP staff.
- Coordinate the field review of a photogrammetric project to determine the suitability of photogrammetric surveying methods.
- Coordinate District aerial photography and mapping databases.
- Authorize the acquisition of photography by the aerial photography service provider once the Party Chief has communicated that the area is ready for photography.
- Maintain familiarity with photogrammetry contracts and specifications, and new photogrammetric methods.
- Coordinate photographic reproduction work with OoP.
- Coordinate the review of consultant photogrammetry projects.
- Assist public and private entities with research of photogrammetric products available within the District.

13.3-6 Office of Photogrammetry (OoP)

The various Branches and Units within OoP perform specialized tasks and work cooperatively to produce photogrammetric products.

The specialized tasks performed by OoP staff include quality control and quality assurance (QC/QA) of photogrammetric work by contractors as well as performing photogrammetric work directly.

The following are the responsibilities of the OoP Branches and Units.

Photogrammetry Project Management

Photogrammetry Project Management is responsible for coordinating the resources of the OoP.

It is the responsibility of the Photogrammetry Project Management Coordinator to:

- Ensure the Department's goals for photogrammetry project delivery are met.
- Negotiate with the Project Manager work agreements to secure resources for photogrammetry project activities.
- Confer with the DPC, Project Manager, and Design Engineer on photogrammetry project matters and resource allocations.
- Act as the primary liaison with the DPC.
- Prioritize photogrammetry projects within OoP.
- Schedule photogrammetry projects and maintain photogrammetric project status databases.
- Receive Photogrammetric Service Requests and assign work to the appropriate OoP Unit.
- Monitor and maintain OoP databases.

Flight Planning

The Flight Planning Unit is staffed with surveyors within the Contracts and Flight Planning Branch in OoP.

It is the responsibility of the Flight Planning Unit to:

- Assign mapping and aerial photography service contract order numbers.
- Review mapping limits and requested products submitted by the DPC on the Photogrammetric Service Request.
- Obtain resource grade base-maps of an area where engineering grade photogrammetry mapping is requested.
- Plan the flight lines and the photo control layout for all precision photography.
- Produce working maps for field crews and aerial photography contractors.
- Provide approximate coordinates of all planned photo control.
- Produce the contract order letter.
- Perform quality checks and contract compliance checks on photographic products.
- Monitor and contribute to OoP databases.

Aerotriangulation

The Aerotriangulation Unit is staffed by surveyors and photogrammetrists within the

Production Branch of OoP.

It is the responsibility of the Aerotriangulation Unit to:

- Plan and execute photogrammetric control densification (Aerotriangulation).
- Work with the DPC to resolve photo control issues.
- Review and approve flight plans.
- Assist in checking the quality of the photography.
- Maintain a camera database.
- Manage aerotriangulation records.
- Monitor and contribute to Oop databases.

Mapping

The Mapping Unit is staffed with surveyors and photogrammetrists within the Production Branch in OoP.

It is the responsibility of the Mapping Unit to:

- Produce digital topographic and planimetric mapping, digital orthophotos and other products by using photogrammetric methods.

Quality

The Quality Branch is staffed with surveyors and photogrammetrists in OoP.

It is the responsibility of the Quality Branch to:

- Perform QC/QA when appropriate.
- Perform accuracy checks on all photogrammetric mapping produced by or for OoP.
- Check photogrammetric mapping for compliance with the Department's CAD standards.
- Monitors and contributes to Oop databases.

Terrain Data

The Terrain Data Branch is staffed with surveyors in OoP.

It is the responsibility of the Terrain Data Branch to:

- Check mapping for digital terrain model (DTM) adequacy.
- Create DTMs from photogrammetric mapping.
- Incorporate field survey data into the photogrammetric DTMs.

Contract Administration

The Contract Administration unit is staffed with surveyors, transportation engineering technicians, and administrators within the Planning and Contracts Branch of OoP.

It is the responsibility of the Contract Administration unit to:

- Ensure that all relevant processes, workflows, and specifications stated in this chapter are complied with.
- Provide management and oversight for all Caltrans photogrammetry contracts.
- Assign photogrammetric compilation not performed by the Mapping Unit to contract compilation resources.
- Develop and administer contracts for the production of photogrammetric products.

13.4 Initial Photogrammetry Contact

The Project Manager shall consult with Surveys and the DPC on the need for photogrammetry products and services as the work plan is being developed. To make this determination, the Project Manager shall meet with all the functional units that will be participating in the project to gather the information necessary to determine if photogrammetric mapping will be required and to accurately define the scope of that mapping. The Project Manager shall provide complete project information such as scope, products, the use of the products, and schedule to the DPC so that existing terrain data can be researched and utilized, and/or a Photogrammetric Service Request can be prepared and forwarded to OoP.

Fully defining the scope of a photogrammetry project at the earliest stage possible results in fewer changes and has a positive effect on the entire process. Expanding the mapping limits in areas where there is some uncertainty may be better than performing additional mapping later in the project life cycle.

Once the Project Manager confirms that the project will require photogrammetric mapping the Project Manager in conjunction with the Design Engineer shall:

- Define the area to be mapped.
- Establish the priority level and the proposed schedule of delivery of the photogrammetric mapping.

The Design Engineer shall contact the DPC in a timely manner to initiate the photogrammetry work. The areas to be discussed at that meeting shall include:

- The area to be mapped.
- The project datums.
- Potential safety problems.
- Scale of the final mapping.
- The required photogrammetric deliverables and delivery dates.
- The preparation and submittal of the Photogrammetric Service Request.

13.5 Photogrammetric Service Request

All photogrammetric services are initiated by a written request from the Design Engineer. Requests should be submitted to the DPC on a Photogrammetric Service Request form for review and approval. The DPC shall then send the request to OoP.

The Photogrammetric Service Request shall contain the following information:

- Requestor's name, phone number and functional area.
- Approximate mapping limits, defined as thoroughly as possible, to be refined after photography is obtained.
- DTM limits, if different from mapping limits.
- Expenditure authorization(s) and special designation(s).
- County, Route, Kilopost, Post Mile, and key intersections for the beginning and ending of the photogrammetric project.
- Horizontal and vertical datums.
- State Plane Coordinate zone.
- Caltrans Design Plane.
- Photogrammetric products required.
- List of data furnished with request.
- List of existing mapping to be edge-tied.
- Date the photogrammetric products are required. The DPC shall confirm the date with the Photogrammetry Project Management Coordinator.

The following pages contain a blank Photogrammetric Service Request and an example of a completed Photogrammetric Service Request.

See OoP's intranet web site for a downloadable version of this form.

STATE OF CALIFORNIA - DEPARTMENT OF TRANSPORTATION
PHOTOGRAMMETRIC SERVICE REQUEST
 DPD - 3009 (PROPOSED)

Date _____

Requester _____

Division, Mail Stop _____

Phone, E-Mail _____

Project Manager _____

Phone, E-Mail _____

Date all Material Required* _____

Material Required:SCALEC.I.DATUM

___ Topographic Map _____ Horizontal _____

___ Bridge Site Map _____ Vertical _____

___ DTM (Include Limits) _____ CT Design Plane _____

___ X-Sections (Include: Alignment, Limits, & Interval) Zone _____

___ Raster Products _____ Descartes Rectification _____ Ortho Rectification _____ Hardcopy Plot
 (Include: Limits, Location, and ASC of Existing CADD File)

___ Other or Comments _____

Data Furnished:

___ District Map Showing Location _____ Mapping Limits (1"=1000')

___ Flight Plans (1"=1000') _____ Control Plans (1"=1000')

___ Edge Ties, ASC #, Location: (/net/...)

___ Photo Control, Location: (/net/...)

___ DTM Field Survey Files, Location: (/net/...)

___ Other _____

Name _____ Date _____ Phone _____
 District Photogrammetry Coordinator___ **Expedite Project (2 km or less**):**Approved _____ Date _____
 Surveys ManagerApproved _____ Date _____
 DES Photogrammetry Project Management Coordinator*This date should be consistent with the *User's Guide to Photogrammetric Products and Services* Time Requirements.

**Expedite mapping may be longer than 2 km with approval from the Surveys Manager and DES Photogrammetry PM Coordinator.

STATE OF CALIFORNIA - DEPARTMENT OF TRANSPORTATION
PHOTOGRAMMETRIC SERVICE REQUEST
 DPD - 3009 (PROPOSED)

Date 7/11/01
 Requester Dave Lopez
 Division, Mail Stop Design/M3
 Phone, E-Mail 8-457-4203
 Project Manager Gary Sidhu
 Phone, E-Mail 8-457-4474
 Date all Material Required* OCT. 15, 2001

Material Required:

	<u>SCALE</u>	<u>C.I.</u>	<u>DATUM</u>
<input checked="" type="checkbox"/> Topographic Map	<u>1:500</u>	<u>0.5</u>	Horizontal <u>NAD 83 (1991.35) Meters</u>
<input type="checkbox"/> Bridge Site Map	<u> </u>	<u> </u>	Vertical <u>NGVD 29 Meters</u>
<input checked="" type="checkbox"/> DTM (Include Limits)	<u> </u>	<u> </u>	CT Design Plane <u>Z2</u>
<input type="checkbox"/> X-Sections (Include: Alignment, Limits, & Interval)	<u> </u>	<u> </u>	Zone <u>CCS2</u>
<input type="checkbox"/> Raster Products	<input type="checkbox"/> Descartes Rectification	<input type="checkbox"/> Ortho Rectification	<input type="checkbox"/> Hardcopy Plot
(Include: Limits, Location, and ASC of Existing CADD File)			
<input checked="" type="checkbox"/> Other or Comments <u>Mapping addition @ Sut 99 From Messick road to Lincoln road. Widen existing mapping @ sheets 399031w04.dgn thru 399031w12.dgn to the Easterly, and Westerly extents of the wing point control. Please expand the DTM's 9931w1.zip, & 9931w2.zip to include this new compiled data. (see prochk3.doc)</u>			

TO BE COMPLETED BY DES:

Project ASC 9901-31
 Aerial Photo ASC 9913-43D
 Models
 Equivalent Miles
 Flying Estimate \$
 Co., Rte., PM SUT 99 24.4/28.7
 Charge, EA 297300

Data Furnished:

☐ District Map Showing Location ☐ Mapping Limits (1"=1000')
☐ Flight Plans (1"=1000') ☐ Control Plans (1"=1000')
☐ Edge Ties, ASC #, Location: (/net/...)
☐ Photo Control, Location: (/net/...)
☐ DTM Field Survey Files, Location: (/net/...)
☒ Other Please find materials listed above in the D3/pickup/9901-31 Directory

Name Keith Werrbach Date 7/11/01 Phone 8-457-6063
District Photogrammetry Coordinator

Expedite Project (2 km or less):**

Approved _____ Date _____
Surveys Manager

Approved _____ Date _____
DES Photogrammetry Project Management Coordinator

*This date should be consistent with the *User's Guide to Photogrammetric Products and Services* Time Requirements.

**Expedite mapping may be longer than 2 km with approval from the Surveys Manager and DES Photogrammetry PM Coordinator.

13.6 Office Preparation

The Photogrammetry Project Management Coordinator shall assign an aerial service contract number (ASC#) and assign the project to the Flight Planning Unit of the Planning and Contracts Branch after receiving the Photogrammetric Service Request.

The Flight Planning Unit shall conduct or oversee the production of all precision photography flight plans.

The Aerotriangulation Unit shall review and approve all flight plans for use in obtaining precision aerial photography prior to distribution.

13.6-1 Flight Planning

Flight plans are maps depicting the location of the photo control and the beginning and ending of flight lines upon which aerial photography is to be obtained. A flight plan must adequately convey the required information to both the field crews and the aerial photography contractor.

The goal of the flight planning process is to produce a flight plan that will provide the best balance between safety, accuracy and economy. This is accomplished by considering the location and amount of photo control to be set, the number of photographs to be obtained, and the required accuracy of the photogrammetric products requested.

In order to produce an effective flight plan the Flight Planning Unit shall have an understanding of neat models, stereoscopic coverage, relief displacement, and control schemes. See Appendix 13B for more information on these topics.

13.6-2 Planning Basemap

The Flight Planning Unit shall initiate the flight planning process by obtaining an appropriate basemap. These basemaps traditionally have been United States Geological Survey (USGS) 7.5-minute quadrangle maps.

High altitude uncontrolled photography may be used to add information for the flight planning process in areas that have undergone significant changes since the USGS quads were produced. A base map that is a digital composite of USGS quad maps for elevation and location purposes and part aerial photography for increased detail has become the standard for flight planning. After the planning basemap has been obtained or produced, the approximate mapping limits from the Photogrammetric Service Request are plotted on the map. The improved detail achieved using a composite map helps in accurately plotting the mapping limits and in selecting target positions that afford easy access and safety. Satellite images or other imagery can also be used to achieve a more detailed flight planning basemap.

Note. The accuracy of the basemap coordinates is approximately 20 meters horizontally and 10 meters vertically. Coordinates derived from these maps are intended for reference only and are not meant to be the definitive location of the required photo control.

13.6-3 Control Schemes

The Flight Planning Unit shall select an appropriate control scheme. The control scheme selected by the Flight Planning Unit depends on what photogrammetric products will be produced and their required accuracy. It also depends on the following factors:

- Safety.
- The size and shape of the area to be mapped.
- The accuracy requirements of the photogrammetric products required.
- The terrain of the project area.
- Accessibility to areas where photo control is to be placed.

The Flight Planning Unit shall select the appropriate control scheme or combination of schemes from the options below. The flight lines are then laid out on the planning basemap in accordance with that control scheme.

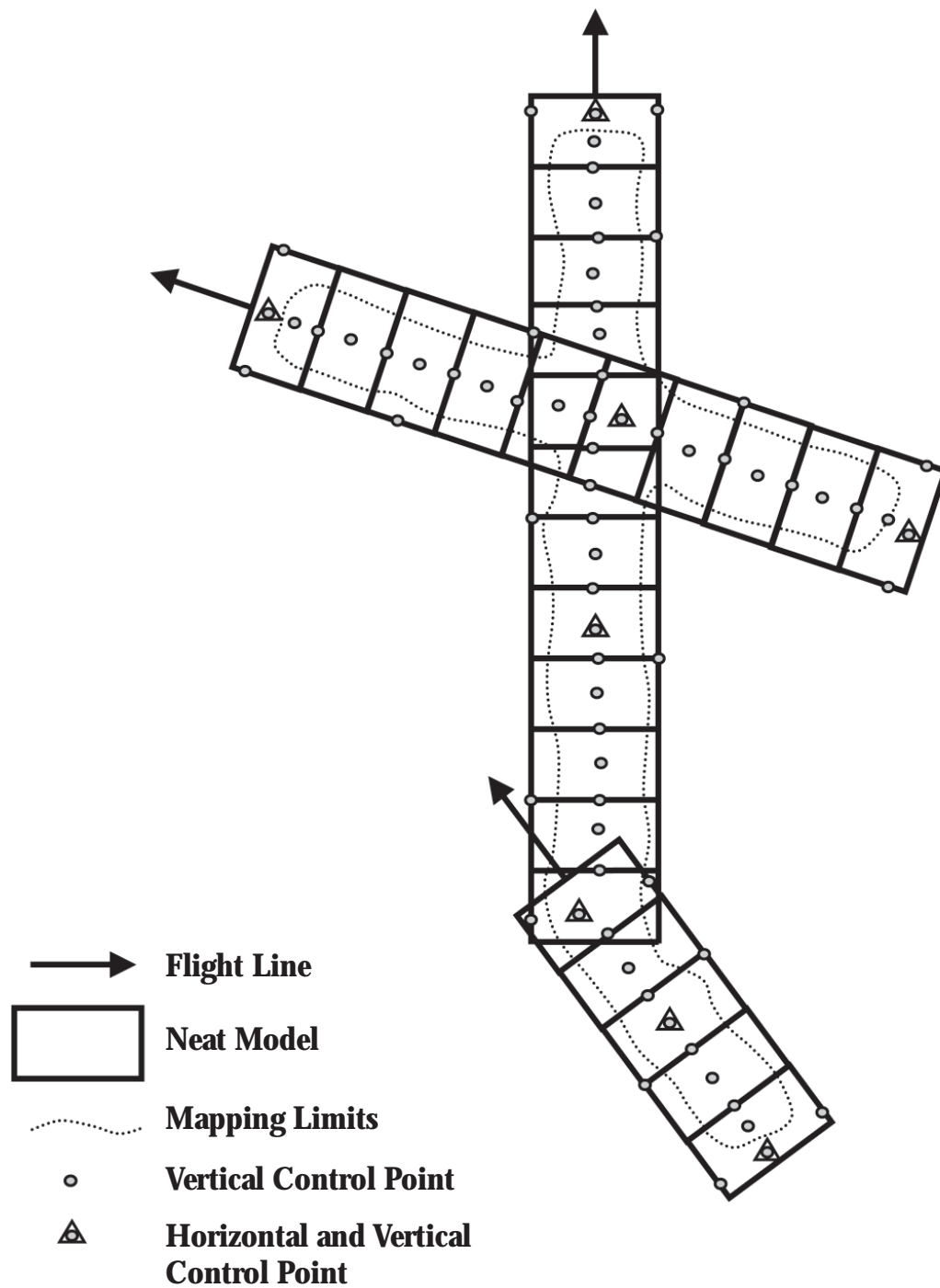
The Flight Planning Unit shall plan adequate photo control in order for the Aerotriangulation Unit to accurately perform their tasks. Through a combination of empirical evidence and research results OoP developed the control schemes below. The amount of photo control required for each control scheme is necessary to reliably achieve the required accuracy for the products to be produced.

The photo control shown on each example scheme are in the ideal positions. These ideal positions are seldom selected because adequate locations close to the ideal positions may be selected by the Flight Planning Unit. The Flight Planning Unit shall consider the following when considering locations of the photo control:

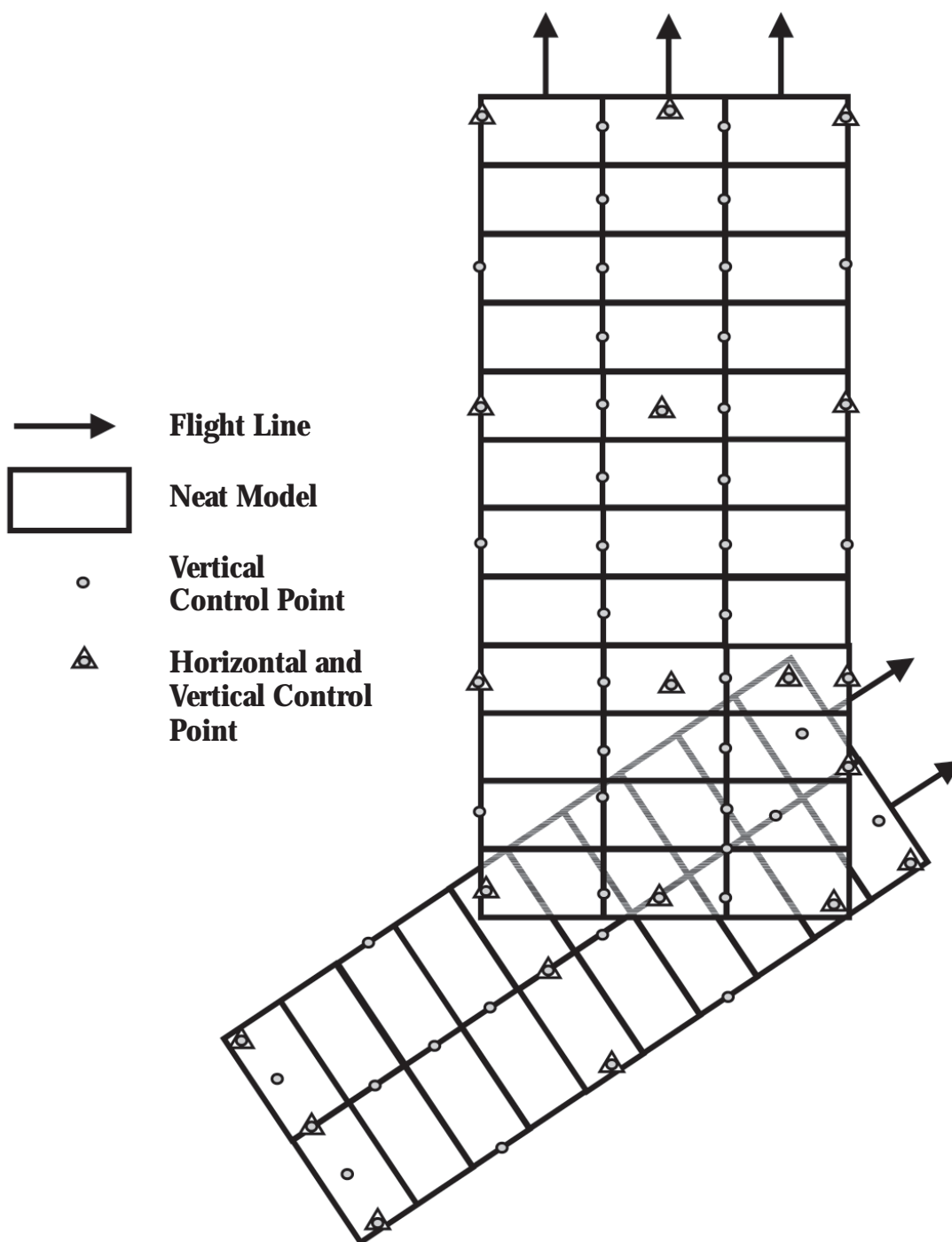
- A safe work zone, such as a surface street with light traffic, as opposed to a freeway.
- Easier access with vehicles, such as a parking lot instead of a golf course.
- A hard surface upon which a durable target can be painted, as opposed to a location that would require a cloth target.
- Other advantages that may be project specific.
- Or any combination of the above.

The following pages depict examples of control schemes and provide information on the purpose of each.

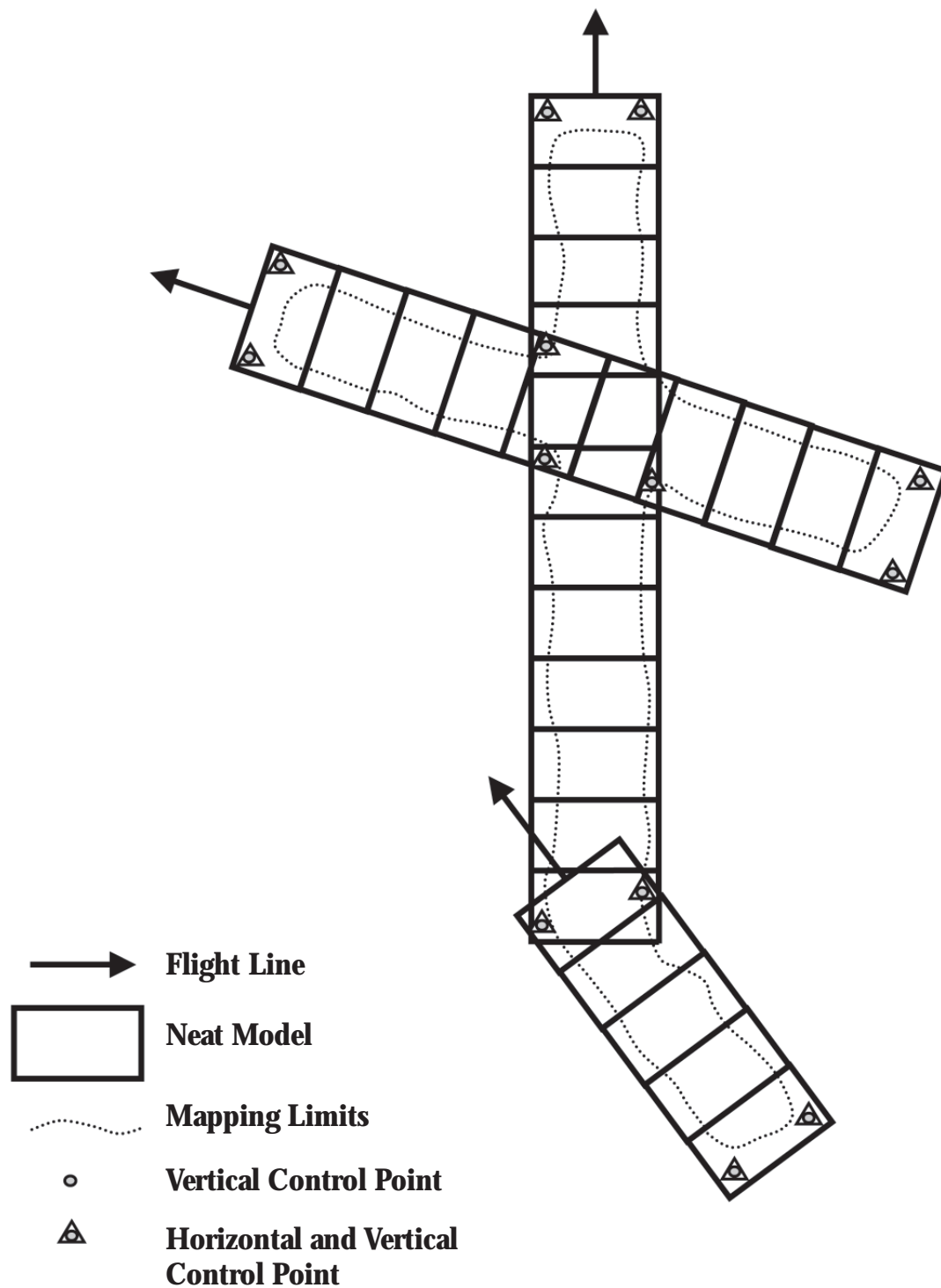
TYPICAL CONTROL CONFIGURATION STANDARD STRIP PHOTOGRAPHY



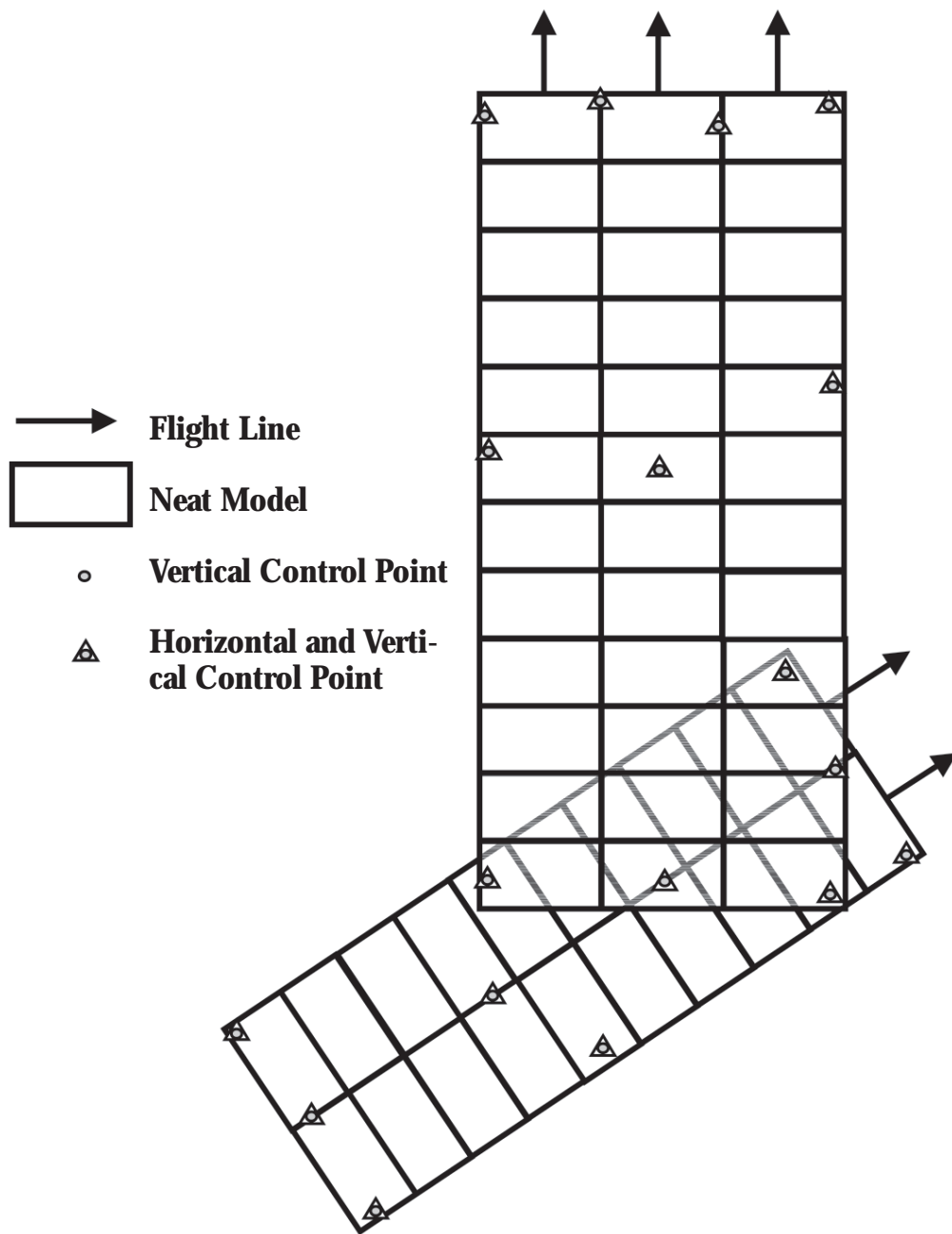
TYPICAL CONTROL CONFIGURATION STANDARD BLOCK PHOTOGRAPHY



**TYPICAL CONTROL CONFIGURATION
STANDARD STRIP PHOTOGRAPHY FOR AIRBORNE GPS**



**TYPICAL CONTROL CONFIGURATION
STANDARD BLOCK PHOTOGRAPHY FOR AIRBORNE GPS**



13.6-4 Mapping Scale

The following chart depicts various mapping scales and their applications.

Mapping Scale and Application

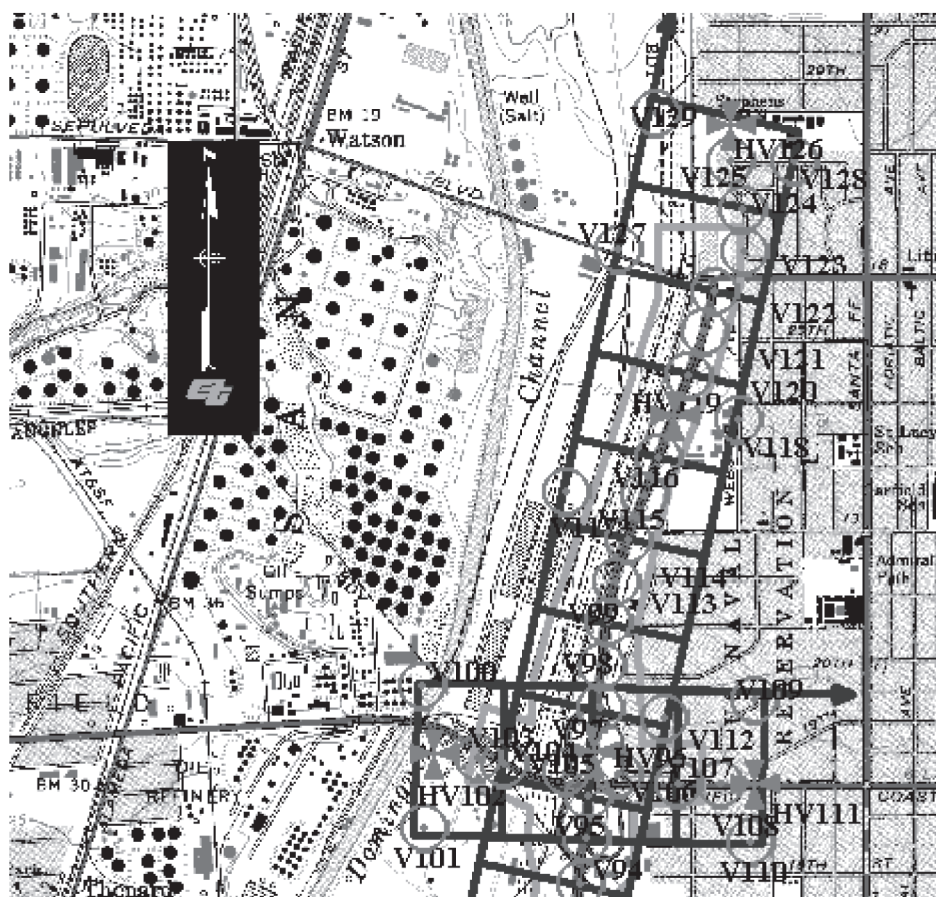
Map Scale	Contour Interval	Mapping Application
1:200	.25 meter	Bridge and Structure Sites
1:500	.50 meter	Standard Mapping for Engineering Design (PS&E)
1:1000	1.00 meter	Environmental, Feasibility, and Planning (PA&ED)
1:2000	None	New Route Corridor Studies

13.7 Flight Planning Deliverables

OoP shall provide the flight planning deliverables to the DPC. The following is the standard delivery package:

- Three copies of the final flight plan. This is a plot of the basemap with the flight lines and the planned locations of the photo control depicted thereon.
- The planned coordinates (in the project datum) for the photo control in both digital and hardcopy format.
- The positional tolerances for movement of the photo control from the planned coordinates, usually shown on the flight plan.
- A copy of the order letter for the aerial photography contract.

The DPC shall review the final flight plan. Any concerns or questions with the flight plan should be resolved with the Flight Planning Unit at this time.



STATE OF CALIFORNIA — BUSINESS, TRANSPORTATION AND HOUSING AGENCY

GRAY DAVIS, *Governor*

DEPARTMENT OF TRANSPORTATION

DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES
OFFICE OF PHOTOGRAMMETRY, MS 35
P.O. BOX 168041
SACRAMENTO, CA 95816-8041



January 9, 2003

CONTRACT 59A0207-A
ASC NO. 0313 ORDER NO. 39A
7-LA-47/103 PM 2.2/4.6-0.0/1.8
07244-200200
MAP ASC NO. 0301-21

ABC PHOTO FLIGHT

123 Main St.
Santa Ana, Ca 92707

In accordance with ASC NO. 0313-39A, please furnish the following services and material along Routes 47/103, in the vicinity of Long Beach.

Pay Items	1110 – Mobilization.
	1211 – Flight time using a 6" focal length camera with 9"x 9" format.
	2112 – Aerial exposures – Stereo coverage with 60% forward overlap, scale, and flying heights, as shown below:

<u>FLIGHT LINES</u>	<u>SCALE</u>	<u>FHASL</u>
1	1:3000	1500'
2	1:3000	1500'
3	1:3000	1500'
4	1:3000	1500'
5	1:3000	1500'
6	1:3000	1500'
7	1:3000	2100'

Flight line 7 is a higher flight of the bridge and river crossing.

3111 – 1 extra set of edited contact prints
4111 – 1 set of photo-index negative with 3 diameter reduction
4211 – 2 sets of photo-index prints.
8212 – **Film diapositives.**

PLEASE DO NOT FLY UNTIL NOTIFIED BY DISTRICT 7.

Sincerely,

ROBERT R GURSS, Chief
Contracts and Flight Planning

Enclosures
cc: Photo Coordinator.
Flying ASC 0313-39A
Map ASC 0301-21

ABC PHOTO FLIGHT
CONTRACT 59A0207-A
ASC NO. 0313 ORDER NO. 39A
January 9, 2003
Page 2

EDITING

Edit photography so the numbers increase in an easterly, thence northerly direction along Route 47 and Route 103. Identification on the negatives shall be:

7- LA-47
7- LA-103

Identification on the photo-index title block shall be:

7-LA-47/103
PM 2.2/4.6-0.0/1.8

DELIVERY

MAIL MATERIAL	DES*	Dist*
PROOF PRINTS	1 SET	
EDITED COLOR CONTACT PRINTS	2 SETS	
PHOTO INDEX NEGATIVE	1 SET	
PHOTO INDEX PRINTS	2 SETS	

**Refer to furnished district and Division of Engineering Services address list.*

SPECIAL INSTRUCTIONS

If you have any questions or need additional information, please call DES in Sacramento at (916) 227-7673, or District Photo Coordinator.

13.8 The Field Package

In cooperation with Surveys, the DPC shall assemble information and materials required for a field crew to successfully complete a photogrammetric control survey including but not limited to the following:

- Three copies of the flight plan showing the planned photo control locations and the positional tolerance for movement of the photo control.
- Data collector files containing the tentative photo control locations and coordinates.
- Control recovery information, and coordinate and/or elevation values.
- Datum and Zone Information.
- Right's of Entry information.
- Property owner contact information.
- Local street maps.

Items required may vary depending on the project area.

13.9 Field Surveys

All photo control surveys shall be conducted in accordance with all of the pertinent requirements of the Department's Surveys Manual.

All photo control targets shall be in place before photography is acquired.

It is recommended that when practical all photo control surveys be completed before photography is acquired.

13.9-1 Placement of Photo Control

Safety

Safety of the field personnel shall be the top priority when placing photo control targets and conducting photo control surveys. Refer to Chapter 2, "Safety" of the Department's Surveys Manual for safety information.

Setting Photo Control Targets

Wherever possible the Party Chief shall set the photo control targets on paved surfaces or other hard surfaces. The targets shall be painted with flat black and flat white paint. If it is not possible to set a target on a paved surface or other hard surface then a cloth target shall be set.

When the location of the target is likely to be disturbed by vandalism, construction, agricultural or other activities, the Party Chief shall set a durable reference monument and the target placed accurately on this mark.

Photo Control Target Placement Tolerance

Each flight plan shall list a positional tolerance that limits the movement of the proposed photo control target from the flight plan location. This is especially important with respect to the wing points. Properly positioned wing points are critical to the aerotriangulation process. In general, the Party Chief may move wing points parallel to the flight line, but the Party Chief should avoid moving the wing points perpendicular to the flight line as the wing point may then fall outside the photography or too close to the middle of the photography, reducing the wing point's effectiveness.

If the limits shown on the flight plan must be exceeded, the Party Chief shall contact the DPC. The DPC, in conjunction with OoP, will determine the best location for alternate photo control.

Photo Control Target Location Tips

The care exercised by the Party Chief in the selection, targeting and positioning of the photo control affects all subsequent photogrammetric processes and the final delivered products.

The planned location of the photo control provided with the flight plan will direct the Party Chief to the general area where the targets are to be placed. Once in the general area, the positional tolerance given on the flight plan and the following tips should be used by the Party Chief to select the final target locations.

Tips on selecting locations for the setting of photo control targets:

- Use the flight plan to anticipate the position of the aircraft and avoid tall objects between the plane and the targets. Stand on the proposed target locations and imagine the plane traveling along the flight line while looking for obstructions.
- Avoid tall objects that may obstruct the image of the target in one or more exposures. If there are unavoidable tall objects near a target then move the target within the tolerances indicated on the flight plan or set insurance targets to ensure that the area will be properly controlled for the subsequent photogrammetric processes.
- Avoid shaded areas. Visit the tentative target locations at the approximate time photography is to be obtained. Relocate the target to a sunny spot if there are shadows in the planned location. Set additional targets if needed.
- Avoid overhead wires. It is difficult for the Aerotriangulation Unit to measure the elevation of the photo control when there are wires suspended above the targets.
- Remove grass from under cloth targets so that the growth of the grass doesn't distort the cloth target between the time it was set and the date of photography. Check the cloth target for "ballooning" caused by growing vegetation immediately prior to ordering photography.
- Choose a level spot if available. A hard surface that will accept paint is ideal, as painted targets are more durable.

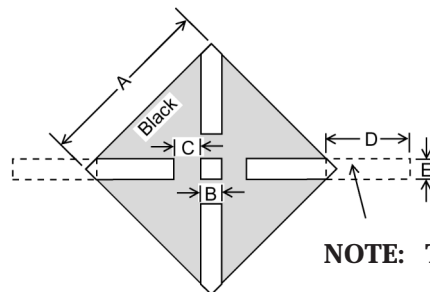
Photo Control Target Orientation Tips

Tips on the orientation of the photo control targets:

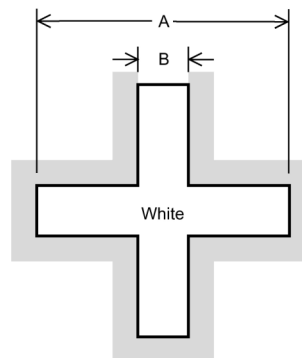
- When possible, photo control targets should be placed so that the legs are aligned perpendicular and parallel to the flight line.
- When photo control targets must be placed on a steep slope, the target should be oriented so that two of the legs that form a straight line lie along the slope at approximately the same elevation.

13.9-2 Target Specifications

CLOTH TARGET



NOTE: This is not part of Cloth Target



TARGET SIZING

Photo Scale	Cloth Target or Painted Replica		Cross	Cross
	1:3000	1:6000	1:12000	1:24000
A	45 in	45 in	12 ft	24 ft
B	4 in	4 in	1 ft	2 ft
C	7 in	7 in		
D	Not Required	24 in		
E	Not Required	6 in		

13.9-3 Accuracy Requirements

The accuracy requirements for photogrammetry surveys stated in Chapter 5, “Accuracy Standards” of the Department’s Surveys Manual shall be met.

All observations on photo control shall be adjusted in a least squares network.

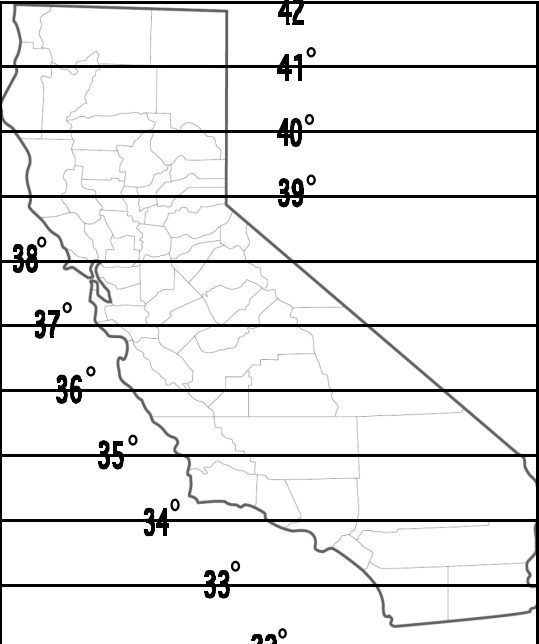
Whenever possible, observations on photo control should be adjusted in a single least squares adjustment.

13.9-4 Solar Altitude Angle and Effects on Aerial Photography

The DPC should advise Surveys in scheduling field surveys to avoid obtaining photography when the solar altitude angles are less than 30 degrees. Precision aerial photography is normally scheduled between 10 AM and 2 PM when the solar altitude angle is highest in the sky. A minimum angle of 30 degrees above the horizon is necessary to avoid long shadows in areas with tall buildings, tall trees, and/or steep terrain. If photography must be acquired during these periods, the DPC should contact OoP for advice. The following chart indicates the dates and times when photography should NOT be taken for various latitudes.

Note: This chart is approximate and was developed from solar altitude nomograms for Pacific Standard Time.

DATES AND TIMES THE SOLAR ALTITUDE ANGLE IS BELOW 30 DEGREES

BETWEEN LATITUDES	Fly Between 10am to 2pm	<u>Do NOT Fly</u>	Fly Between 11am to 1pm
 42°	Feb 22-Oct 17	Nov 9-Feb 7	Feb 8-Feb 21, Oct 18-Nov 8
41°	Feb 19-Oct 18	Nov 12-Feb 4	Feb 5-Feb 18, Oct 19-Nov 11
40°	Feb 16-Oct 19	Nov 15-Feb 1	Feb 2-Feb 15, Oct 20-Nov 14
39°	Feb 14-Oct 23	Nov 21-Jan 29	Jan 30-Feb 13, Oct 24-Nov 20
38°	Feb 12-Oct 27	Nov 27-Jan 23	Jan 24-Feb 11, Oct 28-Nov 26
37°	Feb 10-Oct 31	Dec 3-Jan 17	Jan 18-Feb 9, Nov 1-Dec 2
36°	Feb 8-Nov 5	Dec 9-Jan 11	Jan 12-Feb 7, Nov 6-Dec 8
35°	Feb 6-Nov 9	Dec 15-Jan 5	Jan 6-Feb 5, Nov 10-Dec 14
34°	Feb 2-Nov 16	Dec 15-Jan 5	Jan 6-Feb 1, Nov 17-Dec 14
33°	Jan 29-Nov 19	Dec 15-Jan 5	Jan 6-Jan 28, Nov 20-Dec 14
32°			

13.9-5 Obtaining Aerial Photography

It is the responsibility of Surveys or the Party Chief to keep the DPC informed of the progress of the job so that the scheduling of the photography can be coordinated.

The DPC shall be in contact with the aerial photography contractor prior to the anticipated date of photography to coordinate the scheduling of the flight.

On the day of photography before the photography is obtained the Party Chief shall verify that the photo control targets are in good shape. If any target is missing, a replacement target shall be set prior to photography.

Day of Photography Responsibilities:

District/Region Photogrammetry Coordinator:

- Initiates the aerial photography flight.
- Consults with the Party Chief regarding the weather conditions at the project site.
- Informs the Party Chief when the photography has been obtained.

Party Chief:

- Maintains communication with the DPC regarding weather conditions.
- Informs the DPC of any disturbed targets and sets replacement targets before photography is obtained.
- Ensures that the GPS Base Stations are running if required for Airborne-GPS Photogrammetry.
- Checks the targets to ensure that they are in good shape for the photography.

13.10 Post-Photography Processes

Stereo photographs are the foundation of all photogrammetric products. Good image quality is vital to the efficient and accurate use of photogrammetric techniques, thus good photography quality is important to the photogrammetry process.

The Flight Planning Unit shall examine the photography for endlap coverage, sidelap coverage, stereo coverage, and image quality.

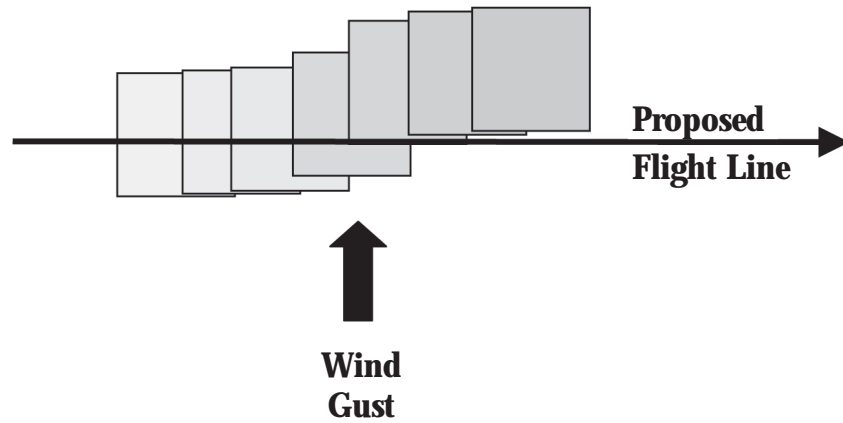
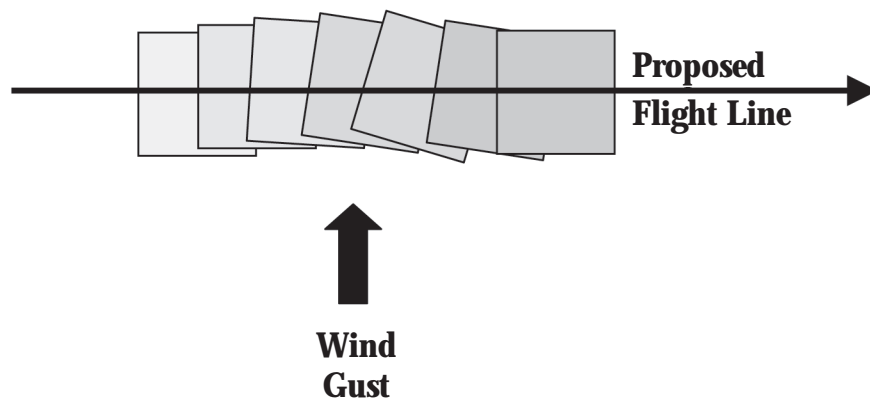
13.10-1 Endlap, Sidelap, and Stereo Coverage

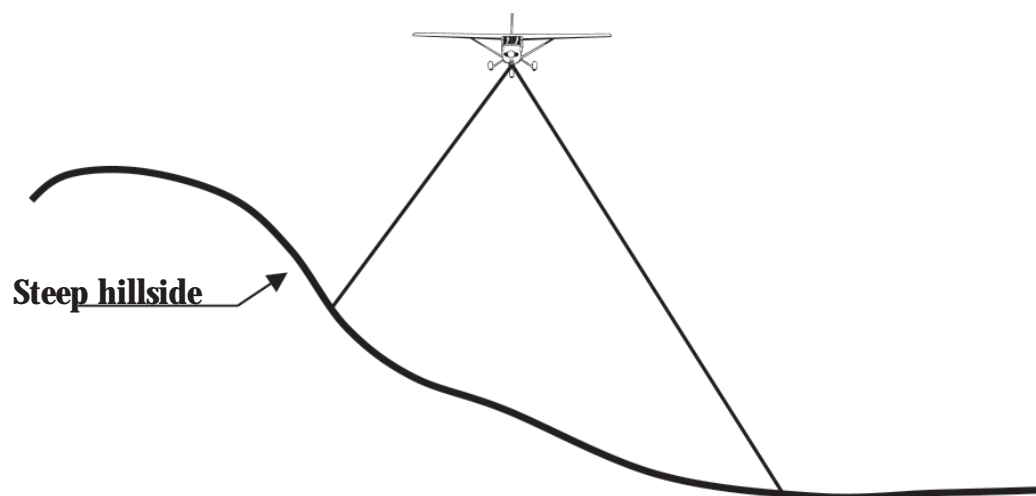
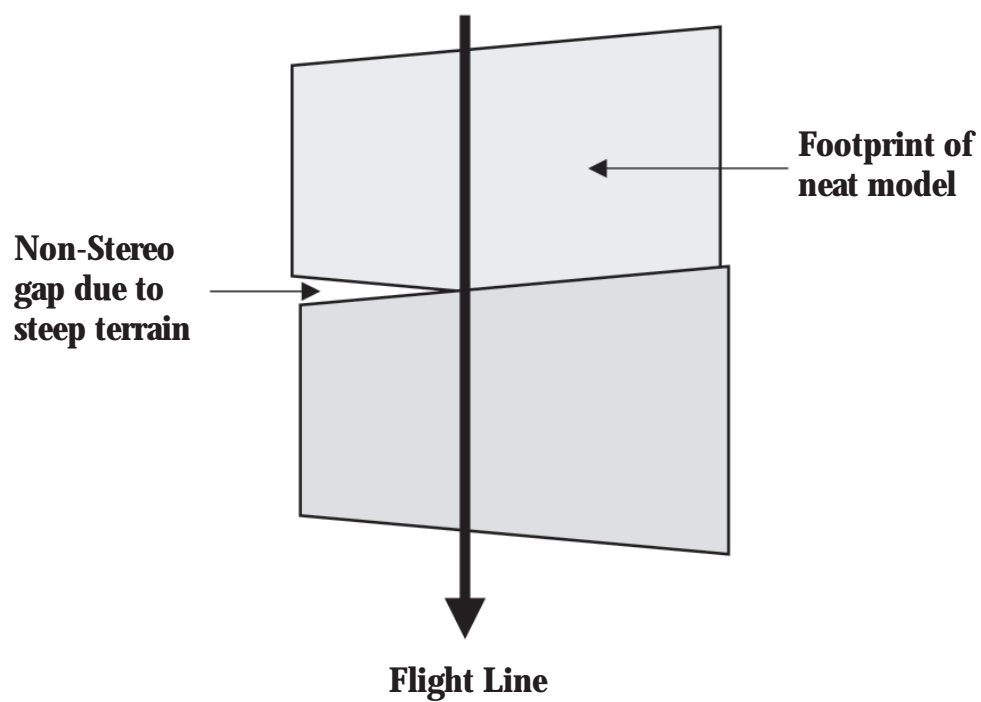
The Flight Planning Unit shall check the aerial photography for the endlap and sidelap coverage between the photos. If the photography lacks adequate endlap and sidelap coverage, then the Flight Planning Unit shall request the photography to be redone. Ideally, the endlap coverage will be 60%; however, endlap coverage ranging from 55% to 65% will produce adequate results. The sidelap coverage percentages will vary with the photogrammetry job.

The Flight Planning Unit shall also verify the stereo coverage within the project limits. It is important to have adequate stereo coverage since an object cannot be mapped if it appears in only a single photograph.

Stereo coverage and endlap can be affected by the flight trajectory of the aircraft. These are most commonly manifested in either crab or drift. Crab occurs when constant corrections to the flight path cause the photos to twist with respect to one another. Drift occurs when the plane deviates from the intended flightline. Examples of each are shown below.

In steep terrain the endlap coverage may need to be increased to avoid sliver shaped gaps in stereo coverage between exposures.

EXAMPLE OF DRIFT**EXAMPLE OF CRAB**

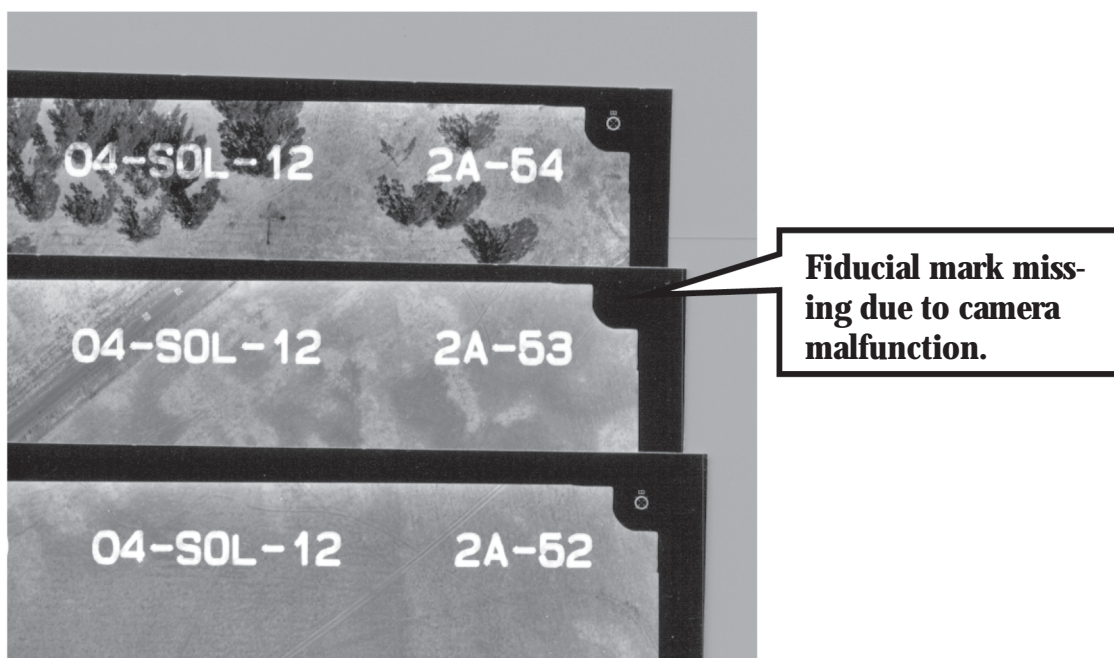
SIDE PROFILE VIEW**TOP OVERHEAD VIEW**

13.10-2 Image Quality

After the Flight Planning Unit has determined that adequate coverage has been achieved, they shall check the quality of the images. Even if the photographs cover the required area, good mapping can be difficult to produce if features on those photographs are not clearly visible.

The qualities the Flight Planning Unit shall check are:

- Image Motion: Elongation of features on the photograph caused by the movement of the aircraft during exposure.
- Halation: Spreading of an image beyond its proper boundaries, particularly common for bright or reflective objects.
- Graininess: Results from poor developing techniques yielding large grain size, decreasing the resolution of the photograph.
- Contrast: The difference in density between the whitest and the blackest areas of the photograph being either too great or too small can cause problems seeing detail, especially in shadowy areas.
- Hot Spot: A bright area of low detail caused by low sun angles.
- Fiducial mark defects: Fiducial marks are imaged by the camera on each exposure and are used to orient photogrammetric instruments to the camera coordinate system. If these fiducial marks are not present photogrammetric measurements cannot be made.

EXAMPLE OF FIDUCIAL ERROR

13.10-3 Marking Control Prints

Surveys shall produce annotated control prints to aid OoP in the location of the photo control in the photography.

Annotated control prints for delivery to OoP are produced from a set of edited contact prints with the following information marked on each photograph:

- All vertical photo control indicated by a red 6 mm diameter circle.
- All horizontal control indicated by a red triangle, 10 mm per side.
- All photo control names neatly printed in red text oriented parallel to the annotation at the top of the photograph.

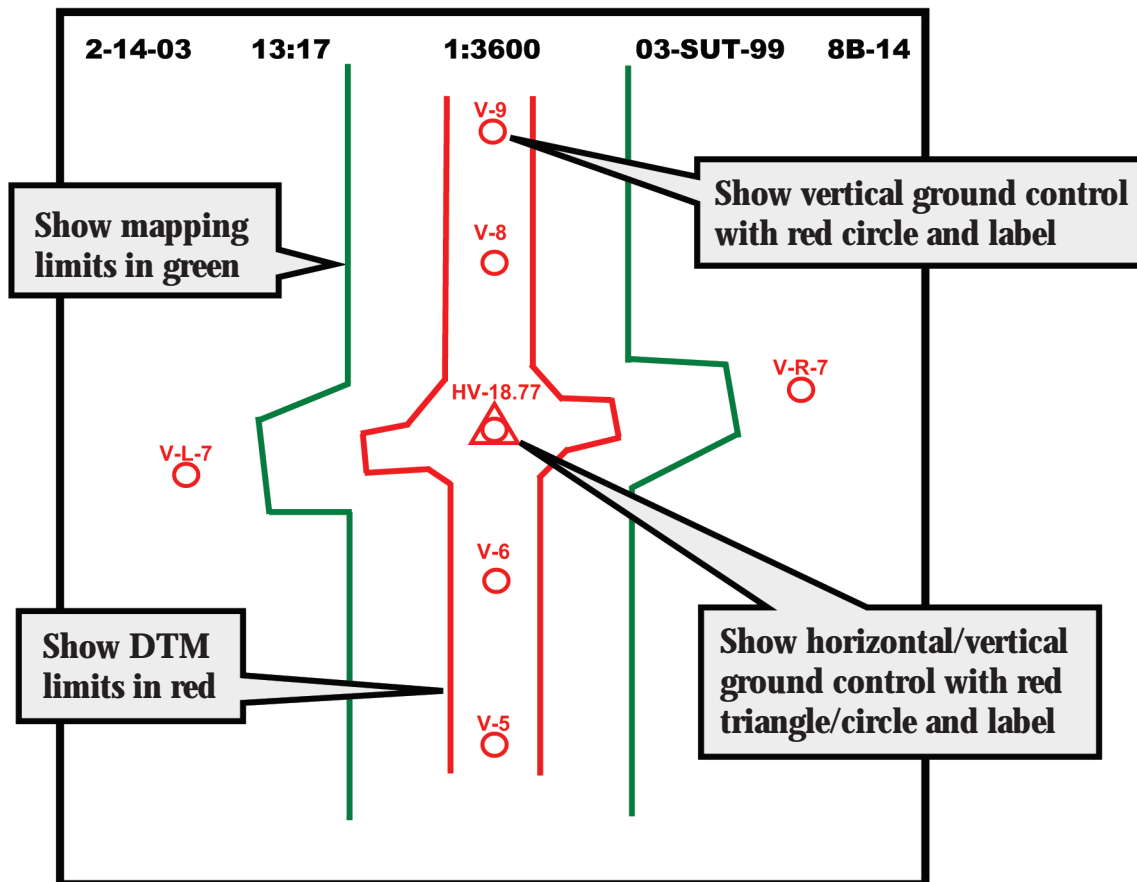
The Design Engineer in conjunction with the DPC shall mark the following limits:

- Mapping limits shown in green and shall form a continuous line over every other photo.
- DTM limits, if different from the mapping limits, shown in red and shall form a continuous line over every other photo.

Photo Identified Control

Occasionally photo control cannot be located in the photography, requiring that a photograph identified control point be established. The Aerotriangulation Unit shall select a distinct point readily identified on both the ground and in the photographs to be surveyed by the Party Chief. The Party Chief shall produce a clear and detailed sketch indicating the field location of this control point. A digital photograph may also be produced.

EXAMPLE OF ANNOTATED CONTROL PRINT



13.10-4 Delivery of Materials and Information to the Office of Photogrammetry

Surveys shall ensure that the photo control data, control prints, and any other pertinent information are delivered to the DPC in a timely manner.

The information delivered shall include:

Control Prints

Delivered and marked as described in section 13-10.3.

Standard Errors

Surveys shall provide adjustment results indicating the standard errors for the photo control so that proper weights can be applied to the photo control in the aerotriangulation process.

TSS File

Surveys shall provide the photo control data to the DPC electronically in the Department's standard format.

The header of the file should include the information shown in the example below.

SAMPLE – PHOTO FILE FORMAT

NOTE: For the file name, use the Mapping ASC number. (e.g. 0001-57.tss)

CALTRANS DISTRICT 7 PHOTOGRAMMETRY UNIT
WDATA CONTROL FILE
WDATA FILE CREATION DATE: 5-26-00

CO-RTE-PM: LA 210 PM 38.6 / 39.8
CHG-EA: 07244-053381

Flightline All
Mapping ASC 0001-57

Photo ASC 0013-67B

DISTRICT 7
SURVEY REQUEST NUMBER: SR 00-065
FIELD SURVEY PARTY CHIEF: Jeff Stevens
CREW MEMBERS: James Stauffer, Jose Andujar, Nestor De Jesus
FIELD WORK COMPLETION DATE: 5-23-00

Provide good header information to properly identify the project parameters. Be sure to include horizontal & vertical datum information.

HORIZONTAL DATUM: NAD 83 CCS ZONE 5 HPGN 1991.35
VERTICAL DATUM: NAVD 88
UNIT SYSTEM: S.I. METERS

NOTES:

Coordinates based on RTK GPS Observations.
Elevations based on Differential leveling using Leica NA 2002 digital level with 3 piece construction bar code rods.

The format is column specific for these information fields.						
POINT NUMBER	TOPO CODE	NORTHING	EASTING	ELEVATION	POINT NAME	POINT DESCRIPTION (USE INPUT / INFO 3)
123456789012345678901234567890123456789012345678901234567890123456789						
1009	140	569811.079	2006982.926	168.272	HV-1	cloth target set rebar & cap
1010	142			167.954	V-12	nail & shinner
1011	141	569560.474	2007624.514		H-8	monument c/l street
1012	140	568867.679	2008629.440	170.068	HV-2	painted target on asphalt

Shipping with Tracking

The DPC shall ship the control prints via a carrier that provides tracking of parcels to minimize the chance that they are lost in shipping.

It is recommended that control prints be shipped using an overnight service. If a receiving record is not received from the OoP the next morning, tracking should be initiated.

13.11 Office of Photogrammetry Mapping Processes

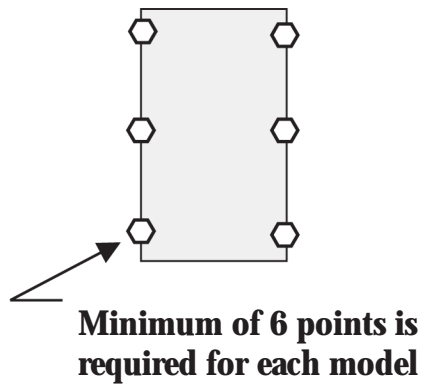
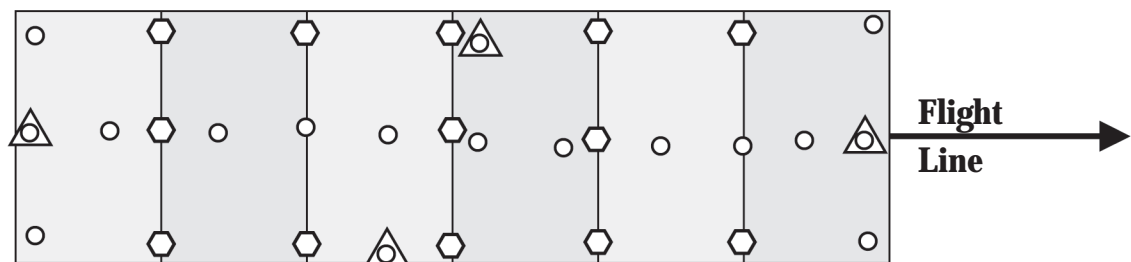
The Aerotriangulation Unit receives the photo control information package from the DPC and is responsible for densifying the control to produce properly controlled stereo models.

13.11-1 Aerotriangulation

Aerotriangulation, also known as analytic bridging, uses mathematical concepts to densify the photo control network with artificial points, also known as analytic points. The analytic points are added to produce adequate control for each stereo model.

Requirements for the analytic points combined with the photo control:

- The analytic points shall have a maximum diameter of 50 microns.
- The combination of photo control and analytic points shall be a minimum of 7 per neat model.
- There shall be an analytic point or photo control at each corner of all neat models.
- The combination of photo control and analytic points shall be a minimum of 3 between two adjacent neat models.
- Tie points shall be created as geometrically warranted between overlapping flight lines.

EXAMPLE OF BRIDGED MODEL**EXAMPLE OF BRIDGED FLIGHT LINE WITH GROUND CONTROL**

- ⬡ Analytic Point
- Vertical Ground Control
- ⬠ Horizontal & Vertical Ground Control

Mensuration

The Aerotriangulation Unit shall place the photographs into a stereoscopic instrument where the positions of the photo control and the marked analytic points are measured.

Requirements for the mensuration of the fiducial points:

- The affine transformation residuals shall be a maximum of 20 microns for each fiducial point.
- The standard error of the mean of the affine transformation fiducial points shall be a maximum of 6 microns.

Requirements for the mensuration of the photo control and the analytic points:

- The relative orientation shall be achieved prior to mensuration.
- The maximum residual shall be 20 microns on the mensuration of a photo control or analytic point.
- The standard error of the mean shall have a maximum value of 6 microns for the mensuration of the photo control and analytic points.
- No mensuration shall take place outside of a neat model's symmetric plane.

Aerotriangulation Adjustment

The Aerotriangulation Unit shall process the measured positions of the photo control and the analytical points with an independent unconstrained adjustment to determine if there are any problems with the photo mensuration.

Any concerns with respect to the aerotriangulation measurements of the photo control and the analytic points shall be resolved. The Aerotriangulation Unit shall examine errors that may have occurred in the aerotriangulation process to resolve any discrepancies.

The Aerotriangulation Unit shall then place the values of the photo control into the input data in order to perform a constrained adjustment.

Requirements for the analysis of the constrained aero triangulation adjustment:

- The standard error of the mean of the adjusted image shall have a maximum value of 5 microns.
- The standard error of the mean of the adjusted photo control and analytic point's elevation shall have a maximum value of 1/10,000 of the flying height.

- The standard error of the mean of the adjusted photo control and analytic point's horizontal coordinates shall have a maximum value of 1/15,000 of the flying height.

To complete the aerotriangulation process the position and attitude, or tilt, of the aircraft at each exposure, or exposure station, is determined by the Aerotriangulation Unit by resecting the position from the known photo control. The values of the unknown analytic points are then determined by performing an intersection from two or more exposure stations through the analytic points to the ground.

The Aerotriangulation Unit shall doublecheck all areas in the aerotriangulation process to resolve any problems with the adjustment results. If the Aerotriangulation Unit is unable to resolve the problems, then the Aerotriangulation Unit shall notify the DPC of the unresolved problems.

The Aerotriangulation Unit shall provide the DPC with:

- A list of the names of the photo control that is suspected of having problems.
- A written description of the reasons for believing there is a problem with the photo control.
- A list of the aerotriangulation residuals on the suspected problem photo control.

The DPC shall work with Surveys and the Aerotriangulation Unit to resolve any photo control problems. All potential error sources should be examined before asking the Party Chief to reobserve any photo control. Only as a last resort will the Party Chief be asked to reobserve the photo control.

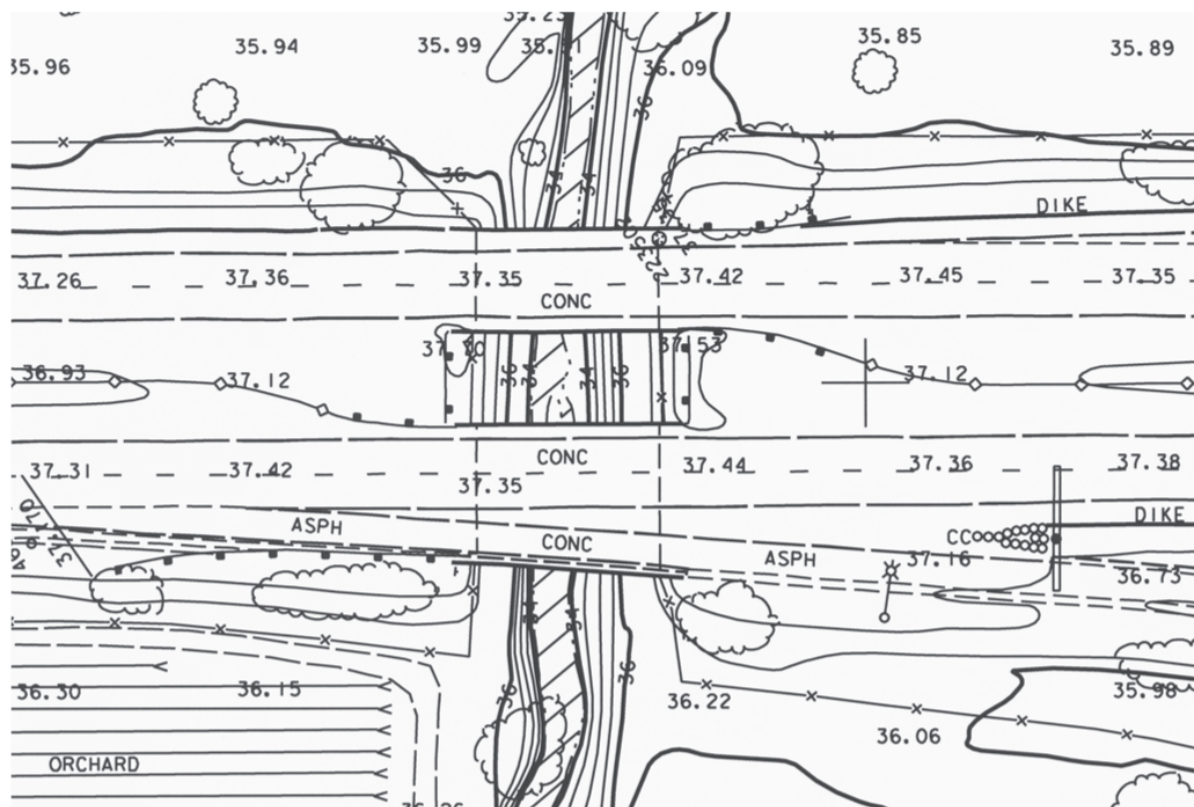
13.11-2 Map Compilation

The production of photogrammetric products begins when aerotriangulation has been completed. There are a variety of photogrammetric products available as indicated in section 13.2-4 of this Chapter and in the Department's User's Guide to Photogrammetric Products and Services. The most common photogrammetric product is 1:500 scale 3D mapping.

The Mapping Unit shall produce 3D mapping by using stereoscopic mapping systems that generate coordinates and elevations for features measured and assigns symbology to those features.

The maps produced are digital three-dimensional vector or point representations of the features photographed. The following is an example of a Department standard 1:500 scale map.

SAMPLE OF TOPOGRAPHIC MAP



13.11-3 Quality

The Quality Branch shall check the completed mapping to verify that it meets Department's mapping standards.

Mapping Accuracy Standards

The standards used by the Department are the "Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways", prepared by The Photogrammetry for Highways Committee of The American Society of Photogrammetry, for the United States Department of Transportation, Federal Highway Administration, 1968. An excerpt of these specifications can be found in Appendix 13C.

Pre-Check

The Quality Branch begins the checking process by examining the maps for file corruption, symbology errors, poor aesthetics, poor coordinates, poor elevations, correct mapping scales, and to ensure proper coverage. If the pre-check does not reveal significant errors the Quality Branch shall grant preliminary acceptance of the maps, informs the DPC of their availability, refers the maps to the Terrain Data Branch for digital terrain model pre-check, and schedules the maps for the comprehensive checking process.

Comprehensive Check

The Quality Branch shall thoroughly check the mapping with a stereoscopic instrument for three-dimensional positional accuracy and compliance with Caltrans' mapping standards. Once errors/omissions have been resolved, the Quality Branch shall grant final acceptance and send the maps to the Terrain Data Branch.

13.11-4 Digital Terrain Models

The Terrain Data Branch is responsible for converting the digital mapping into a three-dimensional digital terrain model (DTM).

Pre-Check

The Terrain Data Branch shall check the preliminary maps for significant errors in symbology and accuracy that would have a negative impact on the suitability of the mapping to be converted into a DTM.

Line Styles Converted to Codes

The Terrain Data Branch shall convert the mapping symbology into a coordinate list with description codes. The coordinates and associated codes are imported into a DTM software package to produce a three dimensional DTM.

Field Data

Additional survey data may be included into the DTM produced by the Terrain Data Branch. The survey data shall be an edited, checked DTM provided by Surveys to the DPC who will then send it to the Terrain Data Branch.

The document, "Standard Delivery Format for Precise Field Survey Data," can be located at OoP's intranet web site.

13.11-5 Final Deliverables to District

OoP will provide the final photogrammetric products to the DPC. Products delivered to the district may include any of those described in section 13.2-4. Typically, the products delivered are 1:500 scale mapping, a DTM, and raster imagery produced by either Descartes or orthophotographic techniques.

It is the responsibility of the Quality Branch to deliver the mapping to the DPC as soon as the quality work is complete.

It is the responsibility of the Production Branch to deliver orthophotography and other raster products to the DPC as soon as the quality assurance process is complete.

It is the responsibility of the Terrain Data Unit to deliver digital terrain models to the District/Region Photogrammetry Coordinator as soon as the quality process is complete.

It is the responsibility of the DPC to review products received and forward them to the requestor.

Appendix 13A: Glossary

Aerotriangulation (AT or Bridging) – Triangulation for the extension of horizontal and/or vertical control accomplished by means of aerial photographs, including such procedures as stereotriangulation, radial triangulation, stereotemplates, and analytic triangulation.

Airborne Global Positioning System (ABGPS) – The use of satellite positioning technology to determine the location of an aerial camera at the moment of exposure. This system will result in a significant decrease in the number of photo control targets required for photogrammetry. The decrease in the number of targets will result in a significant safety advantage for field surveyors.

Analytic Point – A point added to each neat model to produce adequate horizontal and/or vertical control and to eliminate a photo control target that otherwise would have required field survey effort. Also known as an artificial point or a Pug Point.

Basemap – Existing maps and/or photography used for the purpose of planning mapping extents and requirements.

Block – A set of flight lines processed simultaneously to cover an area not possible with one flight line.

Bridging – *See Aerotriangulation.*

Contrast – The difference in density between the whitest and the blackest areas of a photograph.

Control Densification – A process characterized by making small marks in the emulsion of the photographs at ideal positions to control each neat model. These points take the place of photo control that otherwise would have been set on the ground. This makes the photogrammetric process more cost effective by reducing the field work required and allows for mapping in areas that are inaccessible to field crews.

Control Layout – A type of control scheme employed in the production of photogrammetric products. There are a variety of control schemes used by OoP for the production of various photogrammetric products. The appropriate control scheme, or combination of control schemes, is determined by what photogrammetric products will be produced and the required accuracy of those products.

Control Print – A contact print marked with the photo control, DTM limits, and mapping limits.

Crab – The condition caused by failure to orient the camera with respect to the track of the airplane due to side wind.

Digital Highway Inventory Photogrammetry Program (DHIPP) – The program that provides digital geo-referenced ortho-rectified color aerial images of the California highway system for non-engineering applications.

Digital Orthophotography – A digital photographic copy, prepared from a perspective photograph, in which the displacements of images due to tilt and relief have been removed.

Digital Terrain Model (DTM) – A three dimensional model of digital surfaces of topographic features.

Digital Terrain Models (DTM) Limits – The extent of a requested project's three-dimensional digital surface. These limits may vary from mapping limits.

Drift – The lateral shift or displacement of an aircraft from its course, due to the action of wind or other causes.

Emulsion – The coated side or surface of a photographic product consisting of light sensitive material suspended in gelatin.

Endlap – The amount by which one photograph includes the same area as covered by another photograph along a single flight line, customarily expressed as a percentage.

Fiducial Marks – Index marks rigidly connected with the camera lens through the camera body and forming images on the negative which generally define the principle point of the photograph. If these fiducial marks are not present, photogrammetric measurements cannot be made.

Flight Line – A line drawn on a map or chart to represent the track of the aircraft during the period of taking aerial photographs.

Flight Plan – A map that shows tentative photo control target locations and flight lines.

Floating Mark – The introduction into a stereoscopic image of a distinctive mark that seems to float in the stereoscopic image. The floating mark is the basis for the three-dimensional measurement of a stereoscopic image.

Flying Height – The height of the camera above the mean elevation of the ground at the instant of exposure.

Focal Length – A general term for the distance between the rear node of a lens (or the vertex of a mirror) and the point at which the image of an infinitely distant object comes into critical focus.

Focal Point – A point along the lens axis where the image of an infinitely distant object comes into critical focus. ***See also Focal Length.***

Grain – One of the discrete silver particles resulting from the development of an exposed light sensitive material.

Graininess – Large grain size resulting in lack of detail.

Ground Control – ***See Photo Control.***

Halation – The spreading of an image beyond its proper boundaries, particularly common in bright objects.

Hot Spot – A bright area of low detail caused by low sun angles.

Image Motion – Smears in the photography caused by the movement of the aircraft during exposure.

Index Map – A map that shows the position and relationship of all map sheets to each other, as compiled for a survey project.

Insurance Target – An additional target placed to guarantee adequate photo control when there is a reasonable expectation that an existing target will be obscured or destroyed.

Light Detecting and Ranging (LIDAR) – A system that provides a high point density DTM of a site by using a laser to scan the terrain producing a large number of geo-referenced points.

Map Compilation – A collection of observable points to create a three dimensional vector representation of photogrammetric measurements of the Earth's surface.

Mapping Limits – The required extents of mapping needed for a project.

Mensuration – The act of measuring photo control and marked analytic points through the use of a stereoscopic instrument. These observations can be measured to an accuracy of 3/1,000,000 of a meter, or 3 microns, on the image.

Neat Model – The area common to two photographs lying between the principal points of each photograph.

Overlap – The common area between adjacent photography, customarily expressed as a percentage.

Photo Control – A targeted position with a known x, y and/or z coordinate that can be observed in the photography and used as a reference in the aerial triangulation process.

Photogrammetry – The art, science, and technology of obtaining reliable information about physical objects, and the environment, through processes of recording, measuring, and interpreting images and patterns of electromagnetic radiant energy and other phenomena. (**Manual of Photogrammetry**, 4th Ed., ASPRS, 1980)

Photogrammetry Service Request – A form used to request any photogrammetric product.

Photography Identified (PID) Control Point – A distinct point readily identified on both the ground and in the final aerial photography to help control the photogrammetry process.

Photo Rectification – A simple correction of photographs to known ground positions so the images can be used for public display and other non-engineering functions

Photo Scale – The relationship existing between a distance on a photograph and the corresponding distance on the earth. Photo scale may be expressed as an equivalence, usually by different units, that is, 1 inch = 1 kilometer; or as a numerical fraction or ratio, 1/3600 or 1:3600.

Photo Terrain Line (PTL) – High precision Photogrammetry where the photographs are taken from a helicopter.

Planimetric Map – A map which presents the horizontal positions only for the features represented; distinguished from a topographic map by the omission of relief in measurable form.

Planimetry – 1) The science of measuring plane surfaces. 2) Parts of a map which represent everything except relief.

Principal Point – The foot of the perpendicular from the interior perspective center to the plane of the photograph (i.e., the foot of the photograph perpendicular. Also known as the indicated principal point (IPP).

Relief Displacement – The displacement of images radially inward or outward from the nadir point of the photograph. It is caused by differences in elevation of the corresponding ground objects whether below or above, respectively, the elevation of the ground nadir.

Satellite Imagery – Images provided by satellites.

Scale of Photography – *See Photo Scale.*

Sidelap – The amount by which one photograph includes the same area as covered by another photograph lateral to the flight line, customarily expressed as a percentage.

Solar Altitude – The angle between the horizon to the sun.

Stereoscopic Coverage – The total area of a project contained within neat models.

Strip – A group of adjacent photographs taken in a single direction at a predetermined altitude. *See also Flight Line.*

Tilt – The angle at the perspective center between the photograph perpendicular and the plumb line; also, the dihedral angle between the plane of the photograph and the horizontal plane.

Topographic Map – A map of the features of the actual surface of the earth considered collectively as to form. A single feature such as a mountain or valley is termed a topographic feature.

Wing Point – A photo control point located at each of the four corners of the model.

Yaw – *See Crab.*

Appendix 13B:

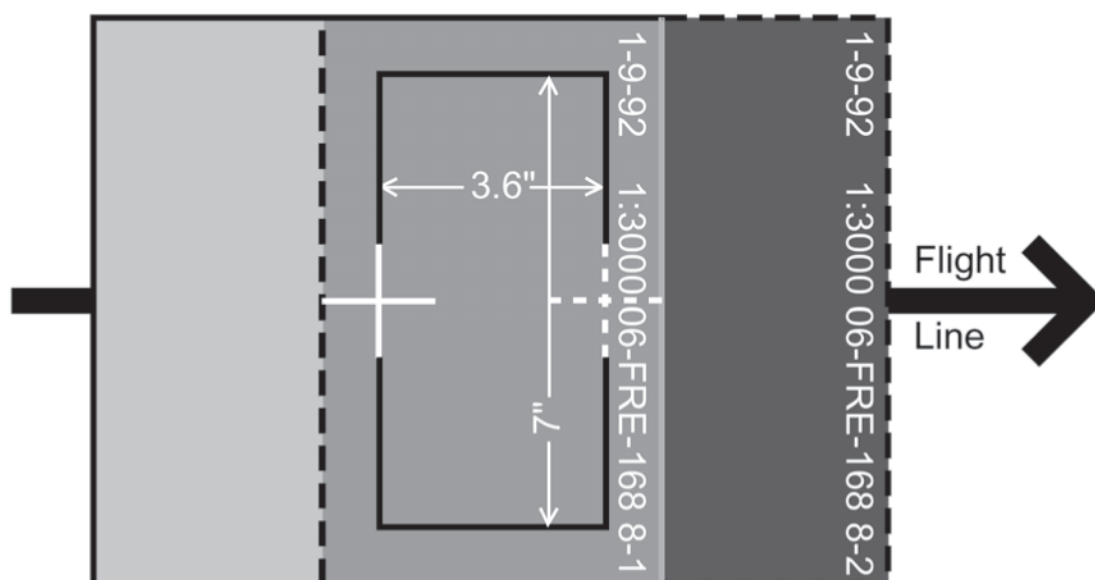
Photogrammetry Basics

Neat Model

The neat model is the basic unit of photogrammetric map compilation and thus the basic unit for all other photogrammetric processes, including flight planning.

The neat model consists of the area common to two sequential photographs in a single flight line, with approximately 60% overlap between them, lying between the principal (center) points of each photograph and approximately one inch from the edge of each photograph.

STEREO NEAT MODEL



The Controlled Neat Model

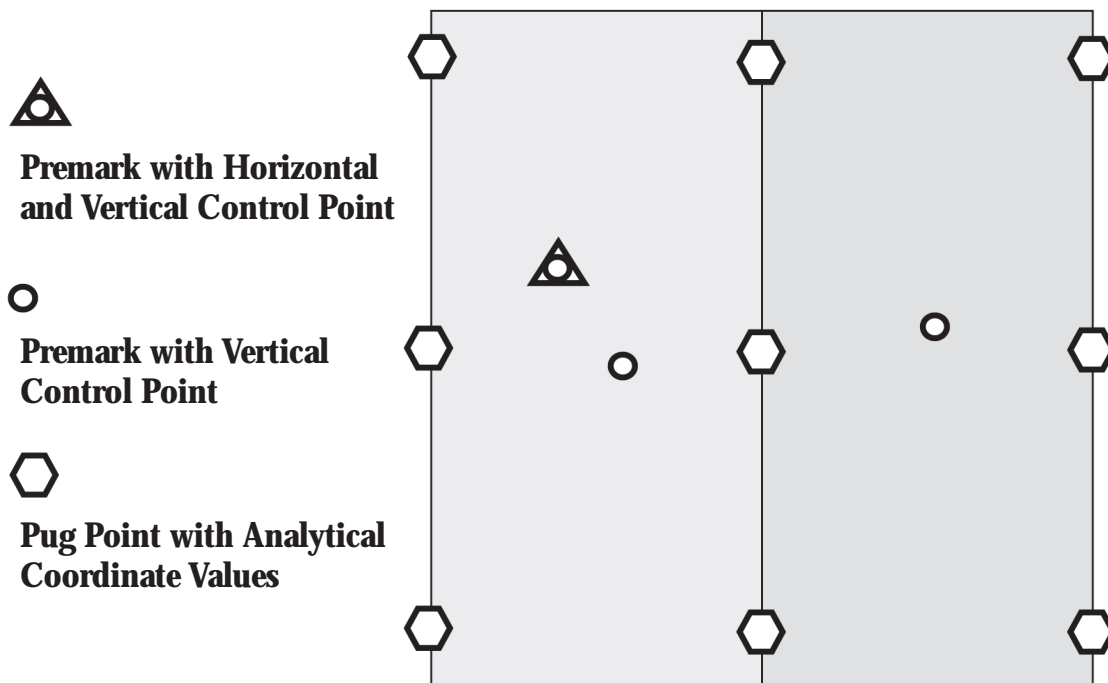
To produce photogrammetric products a neat model must be referenced to the ground by means of control points. Consequently, all steps involved in photogrammetric mapping, prior to the compilation process, are focused on producing well-controlled neat models.

A properly controlled neat model requires the following points:

- Three well distributed horizontal control points.
- One vertical control point at each of the four corners of the model.

Note! A minimally controlled model will have 2 horizontal points and 3 vertical points. This results in single solution, provides no checks and is viewed as poor practice.

EXAMPLE OF TWO NEAT MODELS (FULLY CONTROLLED)



These points can be either traditional premarked targets or analytic points produced by the aerotriangulation process.

Stereoscopic Coverage

The total area of a project contained within neat models is commonly called stereo coverage, or more precisely stereoscopic coverage. The area in which mapping can be performed using photogrammetric methods is limited to the area of stereo coverage. Features existing on only one photograph cannot be mapped. This should be taken into account when planning a photography mission.

Photo Scale

The scale of the photography employed in producing mapping is a factor in determining the accuracy that can be achieved from the mapping process. It is important to know what accuracy will be required, and thus what photo scales will be acceptable before proceeding with the flight planning process.

The scale of a photograph is a function of the height above terrain at which the photograph was taken (h) and the focal length of the camera used (f). The focal length is the distance from the optical center of the lens to the plane of focus of the light passing through the lens. The focal length of cameras most often used in topographic mapping is 152mm (6 inches).

$$\text{Scale} = f / h$$

The scale of photography is generally written in the form of a unitless ratio, for example:

1:2400 means that 1 centimeter on the photo is equal to 2400 centimeters on the ground or 1 inch on the photo is equal to 2400 inches, or 200 feet, on the ground.

The following chart depicts standard flying heights employed by the Department when

STANDARD FLYING HEIGHTS

Flying Height	Photo Scale	Mapping Scale and Application
1500 ft	1:3000	1:200 Bridge and Structure Sites
1500 ft	1:3000	1:500 Design Mapping when using AB-GPS for control
1800 ft	1:3600	1:500 Design Mapping in flat urban areas
		1:500 Design Mapping in rural areas with steep terrain
2400 ft	1:4800	1:1000 Environmental, Feasibility, and Planning (PA&ED)
4800 ft	1:9600	1:2000 New Route Corridor Studies

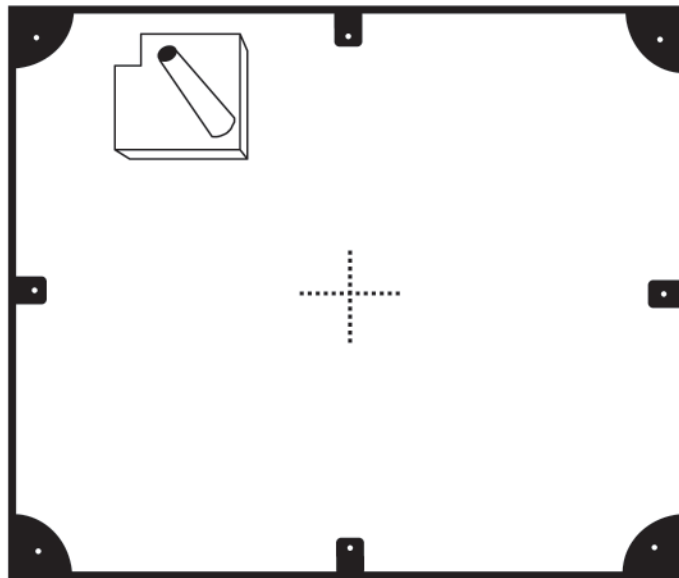
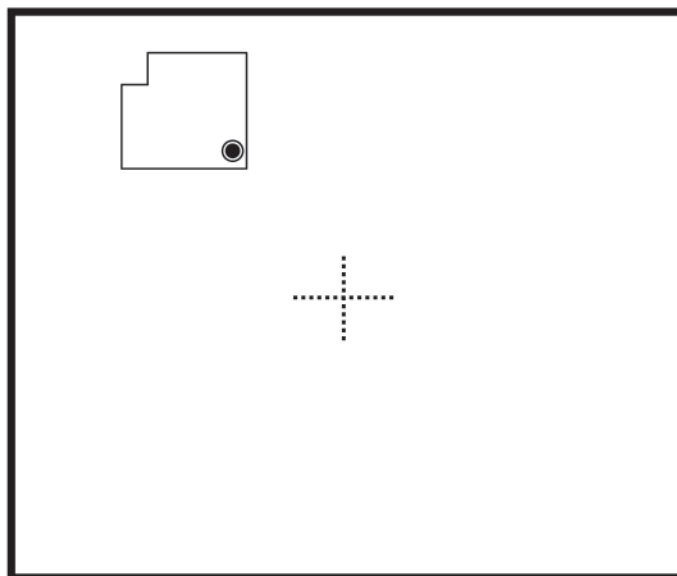
Note:

1. The flying height represents the distance above the average ground elevation along the flight line. The maximum terrain relief along any given flight line shall never exceed 35 percent of the flying height.
2. The flying height is traditionally represented in feet in order to be compatible with the altimeter instrument used in the airplane.
3. Assume focal length (f) to be 152 mm (6 inches).

performing engineering mapping and the accuracy of mapping that can be achieved from those photography scales.

Relief Displacement

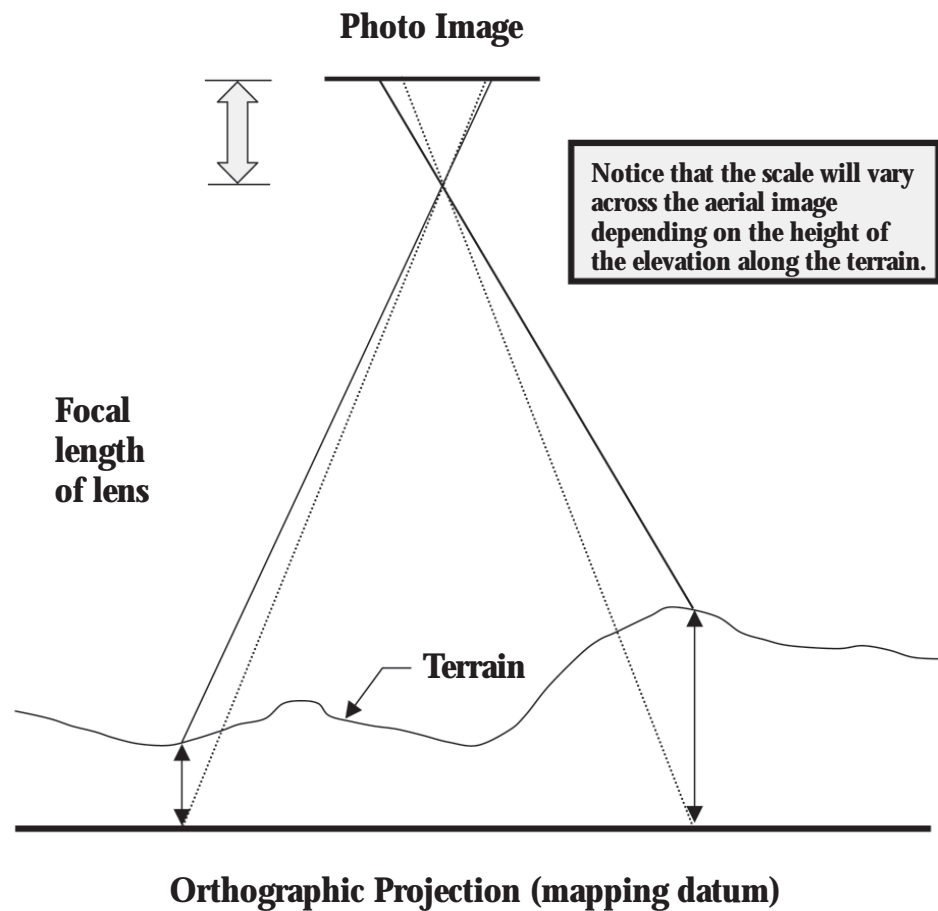
Relief displacement is the apparent leaning of objects within a photograph away from the photo center or principle point. Vertical aerial photographs are good examples of point projections where only the center image is correctly represented in its true position. From the center point outward, all objects are warped (radially displaced) away from the center point. Also, the displacement becomes greater the farther it is away from the center.

VERTICAL AERIAL PHOTOGRAPH**MAP PROJECTION**

Examples of relief displacement can be most easily understood when viewing man-made objects. The graphic below depicts how a tall factory smokestack would appear in an aerial photograph and how it would be represented on an orthographic map projection.

Effect of Terrain Relief on Photo Scale

As discussed above, flying height and focal length determine photo scale. The constant undulations of the earth's surface result in a different flying height above the terrain at



every point within an aerial photograph. This fact causes the scale of an aerial photograph to vary as the elevations of objects within the photograph vary with respect to the exposure altitude of the photograph. Notice how this change in scale affects the photographic coverage of the ground in the diagram below:

As you see, the shorter the distance between the ground and the camera the larger the scale of the photograph at that point. The result is greater ground resolution and the potential for increased accuracy, however the coverage is reduced, increasing the number of photographs and ground control required for mapping a given area. This is where the balance between accuracy and economy has to be maintained.

These changes in ground coverage must be taken into account when planning a photography mission so that adequate stereo coverage for mapping is obtained and control points are properly positioned.

Appendix 13C: Mapping Accuracy Standards

The standards used by The Department are the “Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways”, prepared by The Photogrammetry for Highways Committee of The American Society of Photogrammetry, for the United States Department of Transportation, Federal Highway Administration, 1968.

**Section 60. Planimetric Maps Prepared By
Photogrammetric Methods, Also Profile and Cross Sections**
(Scales ranging from 40 feet to 1,000 feet to one inch)

REQUIREMENTS

60.301 Accuracy.

A. Coordinate Grid Lines – The plotted position of each plane coordinate grid line shall not vary by more than one one-hundredth ($1/100$) of an inch from true grid value on each map manuscript.

B. Horizontal Control – Each horizontal control point shall be plotted on the map manuscript within the coordinate grid in which it should lie to an accuracy of one one-hundredth ($1/100$) of an inch of its true position as expressed by the plane coordinates computed for the point.

C. Planimetric Features – Ninety (90) percent of all planimetric features which are well defined' on the photographs shall be plotted so that their position on the finished maps shall be accurate to within at least one-fortieth ($1/40$) of an inch of their true coordinate position, as determined by the test surveys, and none of the features tested shall be misplaced on the finished map by more than one-twentieth ($1/20$) of an inch from their true coordinate position. The true coordinate position shall be determined by making accurate measurements originating and closing on station markers of the project basic control survey, which shall have a closure accuracy conforming with the requirements for the basic control.

D. Profile and Cross Sections With or Without Mapping – The elevation accuracy in feet of all tested points on profile and cross sections measured photogrammetrically at all centerline stations and at the points of change in ground slope shall be as specified in the itemization schedule, based upon use and conditions as indicated in the Explanation.

E. Special Requirements – When stipulated in special provisions that all specified features (planimetry and spot elevations) shall be delineated on the maps, regardless of whether they can or cannot be seen on the aerial photographs and on stereoscopic models formed therefrom, the consultant shall complete compilation of the required maps by field surveys on the ground so as to comply with all accuracy and completeness stipulations.

F. Spot Elevations – All spot elevations placed on the maps shall be in correct horizontal position to an accuracy of at least one-fortieth ($1/40$) of an inch of their true coordinate position. The root mean square error of the elevation in feet of all spot elevations measured shall not exceed one one-hundred-and-sixtieth ($1/160$) of the map scale expressed in feet to one inch. The elevation in feet of ninety (90) percent of all spot elevations shall be accurate at least to within one one-hundredth ($1/100$) of the scale of the map expressed in feet to one inch, and the remaining ten (10) percent shall be not in error by more than one-fiftieth ($1/50$) of the map scale.

Appendix 13D: Airborne GPS Photogrammetry Surveys

An airborne GPS photogrammetry survey (ABGPS) utilizes Global Positioning System (GPS) technology to determine the three dimensional position of the camera at the instant of each photographic exposure. This results in an 80% reduction in the number of photo control and a corresponding increase in safety for the field surveyors. The safety improvement is created by the almost complete elimination of photo control within the right-of-way. The reduction in the photo control also provides economic and project timeline benefits by decreasing the scope and duration of the work required by Surveys.

The specifications in this appendix are based on a research project conducted by California State University Fresno requested by the Office of Photogrammetry (OoP) and funded by the Division of Research and Innovation. The researchers, in part, conclude and recommend that ABGPS projects reduce the base station and airplane GPS data with post-processed kinematic GPS methods. This process establishes 3D values at the photo center of the photographs, which will then be used in the Aerotriangulation (AT) process. The researchers also recommend that the final AT values be moved to the project vertical datum by imposing a project created geoid separation. The project geoid separation is created from 4 (or more) photo targets that have differentially leveled orthometric heights.

Specifications in this appendix will be revised as more ABGPS projects are performed and evaluated and/or the creation of new ABGPS techniques.

When performing an ABGPS photogrammetry survey, all standards and specifications for conventional photogrammetry survey projects as stated in this chapter shall apply except where modified by this appendix.

13D-1 Responsibilities

13D-1.1 District Photogrammetry Coordinator (DPC)

It is the responsibility of the DPC to:

- Coordinate with Surveys, the Party Chief, OoP, and the aerial photogrammetry contractor for the use of the ABGPS project airport.
- Recommend photogrammetry projects as ABGPS projects to OoP.
- Work with OoP, Surveys, the Party Chief, and the aerial photography contractor to coordinate the schedule of the ABGPS project.

13D-1.2 Party Chief

It is the responsibility of the Party Chief to:

- Set and survey, if needed, the monuments for the base stations.
- Ensure that the provisions of this appendix are met when performing ABGPS surveys.
- Facilitate communication during the flight.

13D-1.3 Photogrammetry Project Management

It is the responsibility of Photogrammetry Project Management to factor GPS processing and adjustments required by ABGPS into resource requests.

13D-1.4 Flight Planning

It is the responsibility of Flight Planning to:

- Use the ABGPS control schemes from Section 13.6-3 as guides to produce flight plans for ABGPS projects.
- Consult with Aerotriangulation on the placement of check points to be targeted on the control scheme for each project.

13D-1.5 Aerotriangulation

It is the responsibility of Aerotriangulation to:

- Provide ABGPS advice and support.
- Process ABGPS data.
- Maintain a GPS antenna and antenna offset database.
- Simultaneously adjust photogrammetric data with ABGPS derived photo center coordinates.

13D-2 Project Selection

The DPC in conjunction with Surveys shall review the project site.

The factors that they shall review are:

- Safety considerations.
- The terrain: Check if the terrain is predominately flat or hilly.
- Suitable GPS environment: See Chapter 6 of this manual for more information.
- Accessibility of potential targets

The DPC shall indicate on the photogrammetry service request if the project is a candidate for use of ABGPS and shall recommend photogrammetry survey projects to OoP for consideration as an ABGPS projects. OoP shall consult with the DPC to determine which photogrammetry survey projects will employ ABGPS. OoP will have the final approval authority for which projects will use ABGPS.

OoP shall select ABGPS based upon the following criteria:

- Recommendation of the DPC.
- Safety – Photogrammetry survey projects shall make use of ABGPS when safety is a major factor.
- Probability of success: The factors that OoP will consider are the terrain of the project area, the proximity of the project to the airport (within 30 km of project site), and the project geometry.

13D-3 Control Requirements

The Party Chief shall perform the ABGPS field survey to the following requirements:

- The base stations horizontal coordinates shall be produced from a Caltrans first order or better GPS survey.
- The base stations ellipsoid heights shall be produced from the survey that produced the base stations horizontal values and have a standard error of not more than 2 cm at the one sigma level from the minimally constrained least squares adjustment.
- The photo control horizontal coordinates shall be produced from a Caltrans second order or better GPS survey.
- The photo control ellipsoid heights shall be produced from the survey that produced the photo control horizontal values and have a standard error of not more than 2 cm at the one sigma level from the minimally constrained least squares adjustment.
- At least 4 photo control points evenly spaced throughout the ABGPS project shall have Caltrans second order differentially leveled orthometric heights.
- Caltrans second order differentially leveled orthometric heights on targets a maximum of every 2 km throughout the ABGPS project. Note: These targets may be additional targets distinct from the photo control and will be used as checks.

See Chapter 5 of this Manual, Accuracy Classifications and Standards.

13D-4 Base Station Location Requirements

Party Chief shall select the base station locations based upon the following criteria:

- One Station within 1 km of the Airport to be used for a static initialization of the airplane GPS equipment.
- One Station within 1 km of each end of the project.
- Additional Stations at 30 km spacing throughout the project.
- GPS suitability.

13D-5 Base-Station Equipment Requirements

Surveys shall provide the following equipment for use at each base-station location:

- A dual frequency GPS Receiver
- A data logger capable of logging data at 2 hertz or better and that has adequate memory for logging data for up to 6 hours.
- A Geodetic Quality Antenna.
- Batteries sufficient to power the GPS equipment for up to 6 hours.
- A fixed height tripod.

13D-6 Airborne Equipment Requirements

The following equipment is required for use in the aircraft:

- A dual frequency GPS receiver.
- A data logger capable of logging data at 2 hertz or better and that has adequate memory for logging data for up to 6 hours.
- An event marker.
- Batteries sufficient to power the GPS equipment for up to 6 hours.
- All necessary cables and adaptors.

13D-7 Mission Planning

The DPC will coordinate with OoP, Surveys, the Party Chief, and the aerial photography contractor the planning of the ABGPS project to optimize the following:

- GPS Satellite configuration: A minimum of 5 or more satellites with a PDOP less than or equal to 4 for the entire period of observation.
- Solar altitude angle and weather conditions that allow for high quality imagery, see Section 13.9-4 for more information.
- The availability of required equipment and personnel
- The availability of the aerial photography contractor.

- A static initialization site for the airplane at the airport that has a good GPS environment and can be taxied to and from without entering areas with a bad GPS environment.

13D-8 Aircraft Equipment Setup

OoP shall approve the aircraft antenna and camera system prior to use on an ABGPS project. The aerial photography contractor shall provide OoP with the GPS antenna specifications and the GPS antenna offset survey data.

The Party Chief and/or OoP shall make the following connections per the aircraft specific checklist provided by OoP:

- Connect GPS receiver to the GPS antenna data only splitter port, the data collector, the event marker, and the battery.
- Connect the event marker to the camera.

If the receiver has a built in event marker then the Party Chief and/or OoP shall make a direct connection between the camera and the appropriate port or jack on the GPS receiver.

13D-9 Preflight Check

The Party Chief and/or OoP shall verify the following for the aircraft GPS equipment:

- Sufficient battery power for the ABGPS project.
- The GPS satellite configuration and the reception of all GPS signals.
- The activation of the camera shutter causes events to be logged in the GPS receiver.

13D-10 Preflight Static initialization

The Party Chief and/or OoP shall collect GPS data for 20 minutes prior to the flying of the project for a pre flight static initialization and again verify that the activation of the camera shutter causes events to be logged. Also, they shall note the camera event number and the GPS receiver event number.

The Party Chief and/or OoP shall authorize the aerial photography contractor to begin the flight upon completion of the pre flight static initialization.

13D-11 ABGPS Flight

The aerial photography contractor shall fly the flight paths shown on the OoP flight plan. Each flight line will be flown twice to minimize the risk of having to repeat the project due to image errors or loss of GPS signal lock.

13D-12 Postflight check

The Party Chief and/or OoP shall verify that the camera events were logged in the GPS receiver after the ABGPS flight. If there is a discrepancy in the number of photographs taken compared to the number of events logged, the discrepancy shall be noted.

13D-13 Postflight Static initialization

The Party Chief and/or OoP shall continue to collect GPS data for an additional 20 minutes after the ABGPS flight for a post flight static initialization.

13D-14 Deliver data to OoP

District Surveys/Region shall deliver the following data to OoP through the DPC:

- ABGPS Receiver Data
- Base-station Receiver Data
- Ground Control Data
- Mapping Epoch Coordinates
- Mission Epoch Coordinates

13D-15 Postmission GPS Processing and Data Analysis

The Aerotriangulation will post process the kinematic data and confer with the DPC the results of the GPS processing.